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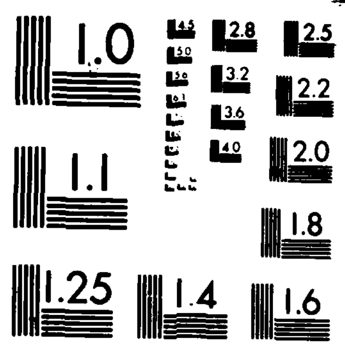

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technical note technical note

Signal Coverage and Characteristics of the Atlantic City Heliport MLS

Barry R. Billman
Donald Gallager
Christopher Wolf
John Morrow
Scott Shollenberger
Paula Maccagnano

November 1986
DOT/FAA/CT-TN86/40

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16. Abstract

During the late fall of 1985 and the winter of 1986 test flights were conducted at the Federal Aviation Administration (FAA) Technical Center's Heliport at Atlantic City International Airport, N.J. The purpose of these flights was to verify signal coverage of the Microwave Landing System (MLS) collocated at the heliport. Other activities included the measurement of the signal characteristics of the Hazeltine Model 2400 MLS which was installed at the heliport. Elevation and azimuth course widths were determined and, using classical Z transform techniques, statistical estimates of control motion noise and path following error were obtained. These estimates were compared with the FAA Standard for Interoperability and Performance Requirements of MLS.

Results obtained were excellent. Tolerance limits were consistently met. The data revealed that wide beam width antenna systems when installed at heliports can meet specification tolerances contained in the FAA specification for MLS Interoperability and Performance Requirements.

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EXECUTIVE SUMMARY

During the late fall of 1985 and the winter of 1986 test flights were conducted at the Federal Aviation Administration (FAA) Technical Center's Heliport at Atlantic City International Airport, N.J. The purpose of these flights was to verify signal coverage of the Microwave Landing System (MLS) collocated at the heliport. Other activities included the measurement of the signal characteristics of the Hazeltine Model 2400 MLS which was installed at the heliport. Elevation and azimuth course widths were determined and, using classical Z transform techniques, statistical estimates of control motion noise and path following error were obtained. These estimates were compared with the FAA Standard for Interoperability and Performance Requirements of MLS.

Results obtained were excellent. Tolerance limits were consistently met. The data revealed that wide beam width antenna systems when installed at heliports can meet specification tolerances contained in the FAA specification for MLS Interoperability and Performance Requirements, FAA Standard 022b.

INTRODUCTION

PURPOSE.

The flight test results presented in this report are part of the ongoing Federal Aviation Administration's (FAA) Program to evaluate the Microwave Landing System (MLS) in conducting precision instrument approaches to heliports. The Hazeltine Model 2400 MLS, which was installed at the Technical Center Heliport, was modified so that signal format conformed to International Civil Aviation Organization (ICAO) standards. Following this modification, flights were conducted to verify system performance. The purpose of this report is to document results of these flights. Previous flight testing had been conducted to determine the impact on accuracy when the MLS employs wide beam width antennas. The results of that testing are compared with FAA Standard 022 (reference 1). That comparison is also documented in this report.

OBJECTIVES.

The specific objectives of the testing documented in this report were:

1. To document signal characteristics associated with the Hazeltine Model 2400 System installed at the FAA Technical Center Heliport.

2. To compare signal characteristics of a wide beam MLS with Standard 022. These characteristics include course bias and estimates of azimuth and elevation control motion noise (CMN) and path following error (PFE).

3. To evaluate Model 2400 System performance following signal format modification using both a System Test And Evaluation Program (STEP) receiver and a Cabin Class receiver.

4. To determine limits of proportional and clearance sector coverage for the system installed at FAA Technical Center Heliport.

5. To verify azimuth and elevation course widths in various segments of proportional coverage.

BACKGROUND.

The Hazeltine Model 2400 System has been used as a test bed by the Helicopter IFR Operations Program. The system has provided precision guidance for development of MLS Heliport Terminal Instrument Procedures (TERPS). The upgrade of the signal structure to the ICAO Standards was necessary for at least two reasons. Testing of an MLS area navigation system (RNAV) will begin early next year. MLS RNAV requires knowledge of ground system antenna location. This information is provided in the data words contained in the ICAO Standards format. Future helicopter MLS application testing requires use of a Cabin Class MLS receiver. The use of this receiver required the implementation of the standard MLS signal format.

To support these requirements, Hazeltine upgraded the signal format to the ICAO Standard format. This work was completed in early 1986. Following this modification antenna alignment was verified using a Flight Inspection Field

Office Sabreliner. Alignment results were consistent with the results obtained prior to signal format modification.

EQUIPMENT DESCRIPTION TEST PROCEDURES

GROUND EQUIPMENT.

The Hazeltine Model 2400 System is located at the FAA's Technical Center heliport. The locations of the MLS antennas in relation to the heliport landing area are shown in figure 1. The precision distance measuring equipment function was supported by a prototype Cardion precision distance measuring equipment (DME/P) system. The Hazeltine Model 2400 MLS characteristics are shown in table 1.

TABLE 1. HAZELTINE MODEL 2400 MLS CHARACTERISTICS

	Azimuth Transmitter	Elevation Transmitter
Beam Width	3.5°	2.4°
Proportional Coverage	up to ± 10°	1° to 15°
Clearance Sector	up to ± 40°	-
Range	20 nmi (minimum)	20 nmi (minimum)
Antenna Aperture Size	5 x 3.5 ft	0.5 x 6 ft
Phased Array Shifters	8	8
Transmitter Power	10 watts nominal	5 watts nominal

nmi = nautical miles

To provide position reference information two separate ground tracking systems were employed during the signal characteristic tests. The first system, called a Precision Automatic Tracking System, is an optical laser tracking machine which was developed by General Telephone and Electronics (GTE). This system was used for a selected number of approaches during the signal characteristic tests. The second tracking system, a Radio Theodolite Telemetry (RTT) system, was used for all the signal characteristic approaches. The RTT system utilizes optical ground tracking equipment and provides a reference signal back to the target aircraft via a very high frequency (VHF) communications link. This reference signal permits differential measurement of several MLS parameters. The description of the system is contained in reference 1.

AIRBORNE EQUIPMENT.

Two different MLS receivers were used. The majority of testing was conducted with the Bendix STEP receiver. In order to verify signal structure

compatability with a Cabin Class receiver, a Bendix MLS 20A Cabin Class receiver was used on a few flights. The characteristics for these receivers are shown in table 2. The major advantage in using the STEP receiver was access to test data for digital recording. Test data were accessed through digital signal interface ports provided in the STEP receiver but not readily available in the Cabin Class receiver.

A full description of the airborne data collection system which was installed in the UH1 helicopter used for this testing can be found in reference 1.

TABLE 2. MLS RECEIVER CHARACTERISTICS

Characteristic	STEP Receiver	Cabin Class Receiver
Frequency Range	5031.00 to 5090.70 MHz	5031.00 to 5090.70 MHz
Frequency Stability	±50 kHz (max)	±25 kHz (max)
Sensitivity	-100 dBm (min)	-106 dBm (min)

PROCEDURES.

Several data collection flights were made to verify MLS signal coverage and course widths. These flights were conducted during a 2-day period in February. Table 3 depicts the purpose for each test run made during this 2-day period. The airborne receiver which was used is also identified.

DATA REDUCTION PROCEDURES.

Several different data reduction procedures were used to obtain the results presented in this report. Signal coverage results were obtained by comparing airborne strip chart recordings with airborne full data rate MLS digital recordings and the technician's flight log, which contained technician and flight crew comments. The full rate MLS digital recording capabilities are discussed in reference 1.

Signal characteristic data reduction procedures were more complex. Figure 2 depicts the processing used to obtain statistical estimates of course bias, CMN and PFE. Two reference tracking procedures were used. The first employed the laser as an independent tracking source requiring post-flight data merging with airborne recordings. The second method was the closed loop RTT method. Data merging was accomplished in real time permitting the airborne digital recording of differential channel values. Differential channel data was then passed through the appropriate filter to obtain a time sequence history of the CMN and PFE filter responses. These time sequence data were merged with laser tracking results to obtain range position information.

TABLE 3. MLS SIGNAL COVERAGE TEST RUN CHARACTERISTICS

Run No.	Receiver	Purpose	Profile
1	STEP	Clearance sector coverage, clearance to proportional transition, proportional sector coverage	360° counter-clockwise orbit at 5 nmi DME and 1500 ft m.s.l.
2	STEP	Same as run No. 1 except orbit was in opposite direction	360° Clockwise orbit, 5 nmi DME and 1500 ft m.s.l.
3	STEP	Azimuth course width, 6° left azimuth	"S" turns to CDI limits during 3° elevation angle approach
4	STEP	Same as run No. 3 except the reference azimuth was the 6° right azimuth	Same profile as No. 3
5	STEP	Elevation course width	Level run at 700 ft m.s.l. resetting reference elevation angle during run
6	STEP	Elevation course width reference elevation angle was 3°	Full fly up to full fly down VDI indications
7	STEP	Elevation course width Reference elevation angle was 2°	Same as run No. 6
8	Cabin Class	Normal MLS approach	0° azimuth/3° elevation to 200 ft DH
9	Cabin Class	Same as run No. 1	0° azimuth/3° elevation to 200 ft DH
10	Cabin Class	Same as run No. 2	0° azimuth/3° elevation to 200 ft DH
11	Cabin Class	Same as run No. 4	Same as run No. 4
12	Cabin Class	Same as run No. 3	Same as run No. 3
13	Cabin Class	Steep elevation angle approach	0° azimuth 7.5° elevation approach to 200 ft DH
14	Cabin Class	Shallow elevation angle approach	0° azimuth/2° elevation approach to 200 ft DH
15	Cabin Class	Elevation course width	Same as run No. 6
16	Cabin Class	Elevation course width	Same as run No. 5
17	Cabin Class	Normal MLS approach	0° azimuth/6° elevation approach

CDI = course deviation indicator
VDI = vertical deviation indicator
DH = decision height

RESULTS

CLEARANCE SECTOR COVERAGE.

Clearance sector coverage was determined by referencing MLS cockpit display and strip chart recorded data to received Atlantic City (ACY) very high frequency omni range (VOR) radial information. The location of the Atlantic City VOR is included in figure 1. Using data recorded in the technician's flight log, strip chart data, and the recorded VOR information, the limits of clearance sector coverage could be defined. Table 4 presents the results of the clearance sector coverage tests. The reference azimuth was oriented on a course of 174°. The nominal limit of clearance sector coverage is 134° and 214°.

TABLE 4. APPROXIMATE CLEARANCE SECTOR COVERAGE LIMITS

Receiver	Profile	Into Coverage VOR Radial Expected	Into Coverage VOR Radial Actual	Out of Coverage VOR Radial Expected	Out of Coverage VOR Radial Actual
STEP	Counter Clockwise	214°	215°	134°	132°
STEP	Clockwise	134°	136°	214°	215°
Cabin Class	Counter Clockwise	214°	222°	134°	131°
Cabin Class	Clockwise	134°	133°	214°	215°

Except for the Cabin Class receiver detecting the clearance sector earlier than expected during the counter clockwise orbit, the results were consistent and as expected. Generally, when entering or leaving the clearance sector a single azimuth flag transition occurred. Boundaries appeared well defined.

CLEARANCE TO PROPORTIONAL SECTOR COVERAGE TRANSITION.

The transition from clearance to proportional sector coverage was observed by selecting either the 10° right or 10° left azimuth with the MLS cockpit control unit and recording the CDI amperage and VOR radial position information on the strip chart recorder. The 0° azimuth reference course is 174° when transitioning into proportional coverage. The transition point was that point at which the CDI amperage change from equivalent full scale (clearance sector indication) to near 0 (proportional coverage at the extreme limits (10° left or right azimuth selected)). When leaving proportional coverage the transition point was that point at which the CDI amperage went from near 0 to equivalent full scale amperage. Table 5 presents clearance sector to proportional sector transition location.

TABLE 5. APPROXIMATE LIMITS OF PROPORTIONAL SECTOR COVERAGE

RCVR	Profile	Clearance to Proportional Transition Radial Expected	Clearance to Proportional Transition Radial Actual	Proportional to Clearance Transition Radial Expected	Proportional to Clearance Transition Radial Actual
STEP	C' Clockwise	184°	183°	164°	163°
STEP	Clockwise	164°	163°	184°	185°
CC	C' Clockwise	184°	186°	164°	164°
CC	Clockwise	164°	165°	184°	185°

The limits of proportional coverage were observed as occurring near the expected locations. Results with both receivers were consistent. Symmetry about the 0° azimuth (174°) was observed within 1° of the nominal 10°.

AZIMUTH COURSE WIDTH.

Several different approaches were made to verify azimuth course width. Course width was checked about two different reference azimuths (6° left and 6° right). The course width was verified by flying "S" patterns about the reference azimuth. The pilot would fly a constant heading until a full scale deflection was observed on his CDI. At this time he would alter course and fly until a full scale deflection in the opposite direction was observed. Results obtained from both the STEP and Cabin Class receivers were similar. Figure 3 depicts the results obtained on run No. 4. The continous tracing of position was overlaid on the 6° right reference azimuth. The cone formed by the two other dashed lines represent the 3.6° course width about the reference azimuth. The extentions of the position tracing beyond limits represent the delays in the pilot's completion of the course reversal following full scale CDI deflection. Similar results were obtained for the 6° left reference azimuth.

ELEVATION COURSE WIDTH.

Level flight data collection runs were flown on the 0° azimuth to determine elevation course width. The level flight segments were flown using the radar altimeter as an altitude reference. The nominal altitude maintained was 640 feet radar altitude, which is about 700 feet m.s.l. attitude. Level flight runs started at a range of 7.5 nmi DME. Figure 4 presents a profile view of results obtained with the STEP receiver during run No. 5. The reference elevation angle for the approach was 3°. Using the recorded slant range, the strip chart recording of VDI displacement and radar altitude, MLS displayed elevation data could be compared with actual aircraft position. Table 6 presents the results.

TABLE 6. LEVEL FLIGHT ELEVATION COURSE WIDTH RESULTS

Event	DME nmi	Display Status	Elevation Angle (Degrees) Expected	Actual
Into elevation coverage	6.70	Elevation flag removed	0.90	0.90
Full scale fly up	3.03	VDI 2 dots low	2.00	1.99
Half scale fly up	2.45	VDI 1 dot low	2.50	2.46
On glidepath	1.99	VDI "0"	3.00	3.04
Half scale fly down	1.72	VDI 1 dot high	3.50	3.51
Full scale fly down	1.56	VDI 2 dots high	4.00	3.87
Out of elevation coverage	0.39	Elevation flag displayed	15.00	15.60

The expected values in table 6 were obtained by using the fact that full scale deflection (2 dot CDI displacement) represents a course width equal to the reference angle divided by 3.

On approach 16 the level flight was again repeated at 700 feet MSL altitude. This time the Cabin Class receiver was used. After verifying the 2° elevation angle course width was ± 0.67°, the control head was successively reset to steeper and steeper reference angles as the aircraft proceeded inbound. Once the on glidepath indication was noted, the reference angle was reset to the next higher value. The results are presented in table 7.

The measured course width for the 2° elevation angle was within 0.02° of what it should have been. Except for the mid-range (3.7° to 5.7°), the elevation angle bias error was less than the tolerance value of 0.06°. However, it is noted that the bias tolerance is established for the bias measured at the approach reference point (ARP). The ARP for heliports is nominally located 1000 feet in front of the elevation antenna. These angle measures were obtained at ranges considerably greater than the range to the ARP.

TABLE 7. ELEVATION COVERAGE RESULTS

Reference (Degrees) Angle	Event	DME (nmi)	Display Status	Elevation Angle (Degrees) Expected	Actual
2.0	Into elevation coverage	6.75	Elevation flag removed	0.90	0.89
2.0	Full scale fly up	4.53	2 dots low	1.34	1.33
2.0	Half scale fly up	3.61	1 dot low	1.67	1.66
2.0	Half scale fly down	2.65	1 dot high	2.33	2.28
2.0	Full scale fly down	2.25	2 dots high	2.67	2.69
3.7	On glide-path	1.67	0	3.70	3.61
5.7	On glide-path	1.07	0	5.70	5.60
6.7	On glide-path	0.90	0	6.70	6.72
7.7	On Glide-path	0.78	0	7.70	7.76
8.7	On Glide-path	0.70	0	8.70	8.67
	Out of elevation coverage	0.35	Elevation flag displayed	15.00	17.50

On run 6, using the STEP receiver and a 3° reference angle, an approach was made in which the pilots flew an "S" pattern in relation to the reference elevation angle. The pilot maintained a constant rate climb until a full scale fly down indication was displayed. He would then initiate a constant rate descent until a full scale fly up indication was obtained. Figure 5 presents the results that were obtained.

MLS SIGNAL CHARACTERISTICS.

Reference 2 identifies the tolerances to be used in determining serviceability of the MLS signal structure. During November 1985, data were collected to verify the serviceability of the Hazeltine MLS installed at the FAA Technical Center Heliport. The purpose of the flights was to evaluate candidate procedures for flight inspecting an MLS installed at a heliport. The data can also be used to verify performance of a wide beam width antenna system. Tolerance limits presented in table 8 were extracted from reference 2.

TABLE 8. MLS SIGNAL TOLERANCE LIMITS

MLS System Component	Signal Error Component	Tolerance Limit at ARP (Degrees)
Elevation	Bias	0.067
	PFE	0.133 at 3° reference angle increasing linearly to 0.199 at 9°
	CMN	0.050
Azimuth	Bias	0.100
	PFE	0.250
	CMN	0.100

FINAL APPROACH SEGMENT BIAS RESULTS.

Azimuth and elevation signal characteristics were verified for a variety of test conditions. The aircraft used in the testing was a UH-1 helicopter. This aircraft was instrumented with a four cue, full three axis flight director and horizontal situation indicator. All approaches were flown manually since the aircraft was not equipped with an automatic flight control system. Data were collected during the entire final approach segment. This segment generally was at least 3 nmi in length. Tables 9 and 10 present the test conditions and estimates of the signal bias error which were obtained.

TABLE 9. FINAL APPROACH SEGMENT FLIGHT TEST CONDITIONS AND BIAS RESULTS FOR ELEVATION TRACKING

Flt No.	App No.	Display Mode	Airspeed (Knots)	Ref Angle	Sample Size	Bias Error (Degrees) Mean	Std. Dev.
6	1	Raw data	60	3°	277	-0.0431	0.0283
	2	1 Cue	60	6°	354	-0.0155	0.0241
	3	3 Cue	60	6°	353	-0.0155	0.0180
	4	3 Cue	50	6°	816	-0.0271	0.0358
8	5	Raw data	40	3°	1227	-0.0231	0.0372
	6	1 Cue	40	3°	1454	-0.0161	0.0363
	7	Raw data	40	4°	1278	-0.0220	0.0290
	8	1 Cue	40	4°	1425	-0.0013	0.0304
	9	3 Cue	40	4°	1309	0.0328	0.0459
9	1	Raw data	40	6°	656	-0.0143	0.0378
	2	1 Cue	40	6°	724	0.0039	0.0507
	3	3 Cue	40	6°	642	-0.0053	0.0648
	4	Raw data	40	9°	739	0.2439	0.5950
	5	1 Cue	40	9°	502	-0.0031	0.0588
	6	3 Cue	40	9°	641	-0.0528	0.0735

TABLE 10. FINAL APPROACH SEGMENT FLIGHT TEST CONDITIONS AND BIAS RESULTS FOR AZIMUTH TRACKING

Flt No.	App No.	Display Mode	Airspeed (Knots)	Ref Angle	Sample Size	Bias Error (Degrees) Mean	Std. Dev.
7	1	Raw Data	40	0°	1668	0.0570	0.0389
	2	1 Cue	40	0°	1700	0.0551	0.0416
	3	1 Cue	40	8°R	1500	0.0565	0.0371
	4	1 Cue	40	8°R	1594	0.0802	0.0444
	5	1 Cue	40	8°L	1534	0.0758	0.0408
9	7	Raw Data	40	0°	940	0.0751	0.0423

The different test conditions included different approach speeds, variations in display information presented to the pilot, and different azimuth and elevation reference angles. The bias error on flight 6 approaches met the tolerance limit specified in table 8. The slower approach speeds (40 and 50 knots) and the steeper reference angles of the bias error, at times, exceeded the tolerance limit for the given elevation angle by 0.01° to 0.03°. The results obtained on approach 4, flight 9, indicates the difficulty in manually flying a raw data steep angle approach. The slight increases in bias error associated with the slower airspeeds occurred because of the increased difficulty the pilot experiences in the vertical tracking task at the lower airspeeds.

For all approaches shown in table 10 the azimuth bias error was less than the limit identified in table 8. Very consistent bias error standard deviation results were obtained for azimuth tracking. Data from four approaches on flight 8 could not be reduced.

FINAL APPROACH SEGMENT CMN RESULTS.

CMN is defined as the high frequency error component in the guidance signal. It represents the error component which could affect aircraft attitude and cause control surface motion during coupled approaches. Post-flight analysis of the RTT differential channel data provided estimates of CMN. The RTT differential channel data was used as input to the following high pass transfer function to obtain statistical estimates of CMN.

$$H(s) = s/(s+a) \qquad (1)$$

where
$$a = \begin{cases} 0.3 \text{ radians/second for azimuth tracking} \\ 0.5 \text{ radians/second for elevation tracking.} \end{cases}$$

Since the RTT differential channel was sampled at a 5 Hz rate, classical Z transform methods when applied to equation (1) yield the following difference equations.

$Y_n = 0.97087(X_n - X_{n-1} + 0.97Y_{n-1})$ for azimuth tracking and

$Y_n = 0.95238(X_n - X_{n-1} + 0.95Y_{n-1})$ for elevation tracking

where

X_n = the n^{th} observation of the value of the RTT differential channel

Y_n = the n^{th} high pass filter response.

Elevation CMN: Figures 6 through 20 are the time domain plots of the CMN filter response for elevation tracking. Each plot represents the result obtained during one approach. The ARP, which is 1000 feet in front of the elevation antenna, is also depicted on each plot. The horizontal bands depict the appropriate tolerance limits for each approach. The left side of the plot represents the initiation of the final approach segment. Excellent results were obtained. Only on approach 4, flight 6, did the CMN filter response consistently approach the tolerance limits for elevation tracking.

On a few approaches large CMN responses occurred inside the 1000-foot ARP. However, the tolerance limit only applies to data collected at and outside the ARP. On figure 18 slight excursions beyond the tolerance limits in the CMN filter responses are observed. This resulted due to the increased pilot workload that is experienced when manually flying steep elevation approach angles.

The statistical estimates of the CMN filter response for elevation tracking are presented in table 11.

TABLE 11. STATISTICAL ESTIMATES OF CMN FILTER RESPONSES FOR ELEVATION TRACKING

Flt No.	App No.	Reference Angle	Sample Size	Observed 95% Confidence Limit (Degrees)
6	1	3°	837	0.0501
	2	6°	778	0.0301
	3	6°	860	0.0255
	4	6°	1231	0.0341
8	5	3°	1668	0.0431
	6	3°	1700	0.0398
	7	4°	1500	0.0259
	8	4°	1594	0.0277
	9	4°	1534	0.0313
9	1	6°	930	0.0388
	2	6°	879	0.0316
	3	6°	908	0.0344
	4	9°	711	0.0789
	5	9°	948	0.0516
	6	9°	942	0.0436

Azimuth CMN: Figures 21 through 30 present the CMN filter response for azimuth tracking. Only very minor excursions beyond the tolerance limits for very short time periods are present. Table 12 presents the statistical estimates of the CMN filter response for azimuth tracking. In all cases the specification tolerances were met.

FINAL APPROACH SEGMENT PFE RESULTS.

The PFE is defined as the low frequency error component in the guidance signal. It represents the portion of the guidance signal error spectrum which can cause aircraft dispacement from the desired azimuth course or selected glidepath angle. The RTT differential channel was analyzed using the low pass transfer function shown in equation 2 to obtain estimates of PFE.

$$H(s) = w/(s^2 + 2ws + w^2) \qquad (2)$$

where $w =$ 0.78125 radians/second for azimuth tracking

2.34375 radians/second for elevation tracking.

TABLE 12. STATISTICAL ESTIMATES OF CMN FILTER RESPONSES FOR AZIMUTH TRACKING

Flt No.	App No.	Reference Angle (Degrees)	Sample Size	95% Confidence Limit (Degrees)
7	1	0	1668	0.0495
	2	0	1700	0.0511
	3	8R	1500	0.0566
	4	8R	1594	0.0701
	5	8L	1534	0.0634
8	1	8L	1590	0.0745
	2	8L	1525	0.0743
	3	0	1038	0.0461
	4	0	1301	0.0789
9	7	0	1015	0.0606

Since the RTT differential channel sampling rate was 5 Hertz (Hz) the following difference equations were obtained from equation 2.

$$Y_n = 0.00525(X_n + 2X_{n-1} + X_{n-2}) + 1.7101Y_{n-1} - 0.7310Y_{n-2}$$
for azimuth tracking and

$$Y_n = 0.0361(X_n + 2X_{n-1} + X_{n-2}) + 1.2405Y_{n-1} - 0.3847Y_{n-2}$$
for elevation tracking

where

X_n = n^{th} observation of the RTT differential channel value

and Y_n = n^{th} PFE filter response.

Elevation PFE: Time domain plots of the PFE filter responses for elevation tracking are shown in figures 31 through 45. Although a definite bias is present in some plots, the PFE filter responses for each approach were consistently within the tolerance limits for elevation tracking. The statistical estimates of PFE filter response for elevation tracking is shown in table 13.

TABLE 13. STATISTICAL ESTIMATES OF PFE FILTER RESPONSE FOR ELEVATION TRACKING

Flt No.	App No.	Reference Angle (Degrees)	Sample Size	Tolerance Limit (Degrees)	95% Confidence) Limit (Degree
6	1	3	837	0.133	0.032
8	5	3	1227	0.133	0.032
8	6	3	1454	0.133	0.032
8	7	4	1278	0.144	0.026
8	8	4	1425	0.144	0.027
8	9	4	1309	0.144	0.043
6	2	6	778	0.166	0.031
6	3	6	860	0.166	0.032
6	4	6	1231	0.166	0.033
9	1	6	930	0.166	0.043
9	2	6	879	0.166	0.043
9	3	6	908	0.166	0.058
9	4	9	711	0.199	0.189
9	5	9	948	0.199	0.130
9	6	9	942	0.199	0.124

Statistics on table 13 indicate that PFE was considerably less than the tolerance limits.

Azimuth PFE: The plots of PFE filter responses for each of the azimuth tracking approaches are shown in figures 46 through 55. Although the time ordered filter responses remained within tolerance limits, a definite bias is apparent on the first four approaches on flight 8 (figures 51 through 54). The statistical estimates of PFE for azimuth tracking can be found in table 14.

TABLE 14. STATISTICAL ESTIMATES OF PFE FILTER RESPONSE FOR AZIMUTH TRACKING

Flt No.	App No.	Reference Angle (Degrees)	Sample Size	95% Confidence Limit (Degrees)
7	1	0	1668	0.030
	2	0	1700	0.033
8	3	0	1038	0.018
	4	0	1301	0.034
9	7	0	1015	0.029
7	3	8L	1500	0.026
	4	8L	1594	0.030
	5	8L	1534	0.029
8	2	8R	1525	0.034

Despite the fact that the Heliport MLS employs wide beam width antennas and the ARP for heliport approaches may be only 1000 feet in front of the antennas, excellent results were obtained. The tolerances identified in FAA Standard 022b, the specification for MLS Interoperability and Performance Requirements, were consistently met.

CONCLUSIONS

1. The clearance sector signal coverage provided by the Hazeltine Microwave Landing System (MLS) located at the Technical Center heliport has been determined. Clearance sector coverage was about $\pm 40^\circ$ wide. The transition into or out of the clearance sector generally resulted in only one change in the azimuth navigation flag status.

2. Limits of proportional sector coverage was consistently measured at $\pm 10^\circ$ about the 0° reference azimuth.

3. The azimuth course widths were measured at $\pm 3.6^\circ$. Measures were taken about two reference azimuths, 6° right and 6° left. Similar results were obtained with both the Cabin Class and System Test and Evaluation Program (STEP) receivers.

4. Elevation coverage was verified out to a range of 7.5 miles. The lower limit of coverage was 0.9°, which is expected. This lower limit was measured with both receivers. The upper limit of coverage was measured as 15.6° with the STEP receiver and 17.5° with the Cabin Class receiver. The specified upper limit is 15°.

5. The elevation course width of approach angle divided by 3 was verified for two reference angles, 2° and 3°. Elevation angle alignment was verfied with level flight profiles. Except for some midrange bias errors (3.7° and 5.7°) that approached the elevation bias tolerance limits, proper on-glidepath guidance was provided for all measured reference angles.

6. Even with an azimuth beam width of 3.5° and an elevation beam width of 2.4°, the Model 2400 system met the tolerances established in reference 2. Excellent results were achieved. Estimates of control motion noise and path following error consistently met the tolerance limits specified in FAA Standard 022.

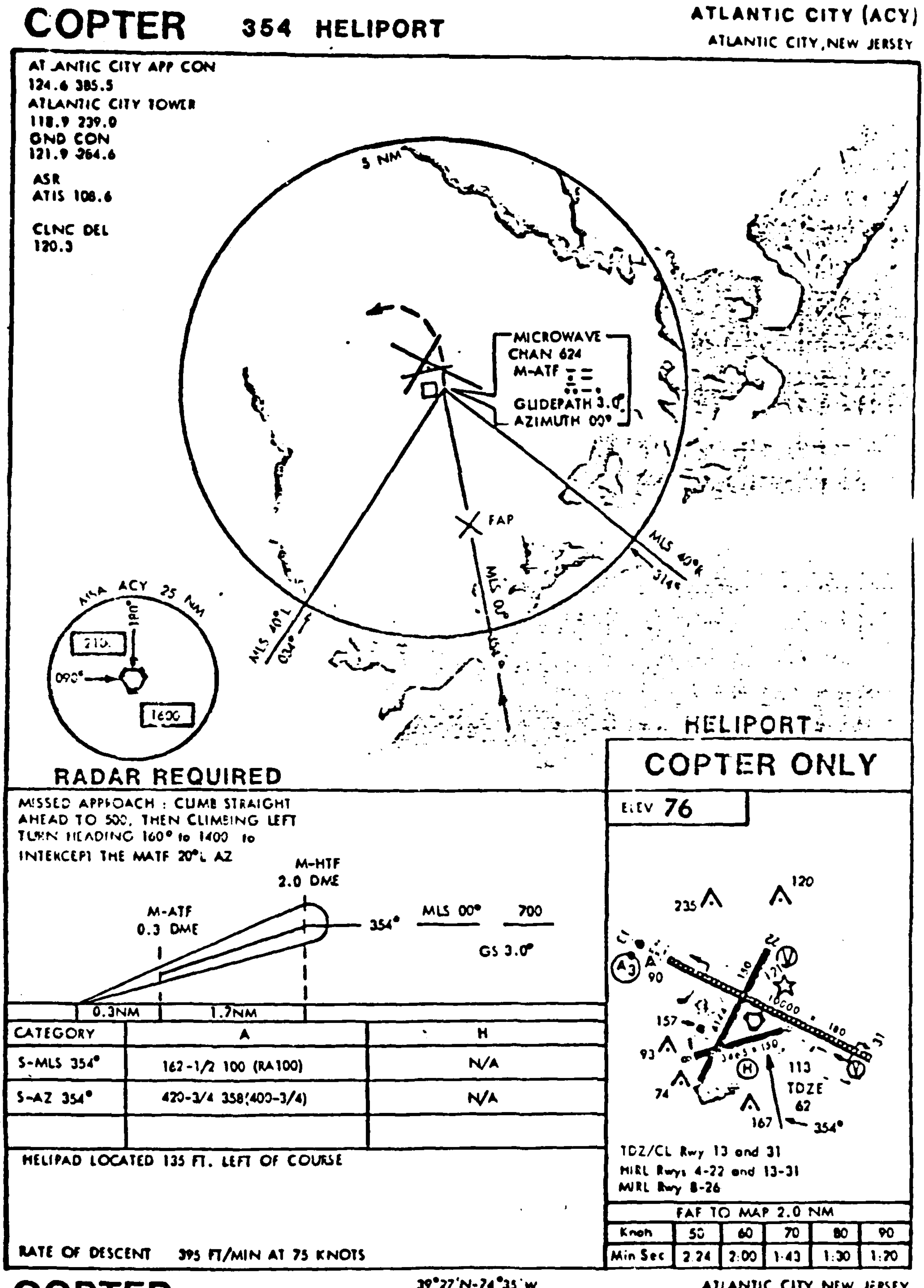
7. If wider beam widths permit smaller packaging of the antenna aperatures, then wider beam width systems should be the choice for installation at heliports due to restricted real estate availability.

8. Tolerances identified in Standard 022b can be met when the approach reference point is as close as 1000 feet to the antennas and approaches are manually flown in a properly instrumented helicopter.

REFERENCES

1. Shollenberger, S. and Billmann, B., Heliport MLS Flight Inspection Project, DOT/FAA/CT-TN86/14, April 1986.

2. FAA Specification for MLS Interoperability and Performance Requirements, FAA Standard 022B, DOT Federal Aviation Administration, October 1983.



CATEGORY	A	H
S-MLS 354°	162-1/2 100 (RA100)	N/A
S-AZ 354°	420-3/4 358(400-3/4)	N/A

HELIPAD LOCATED 135 FT. LEFT OF COURSE

RATE OF DESCENT 395 FT/MIN AT 75 KNOTS

TDZ/CL Rwy 13 and 31
HIRL Rwys 4-22 and 13-31
MIRL Rwy 8-26

FAF TO MAP 2.0 NM					
Knots	50	60	70	80	90
Min Sec	2:24	2:00	1:43	1:30	1:20

COPTER 39°27'N-74°35'W ATLANTIC CITY, NEW JERSEY ATLANTIC CITY (ACY)

FIGURE 1. HELIPORT MLS INSTALLATION

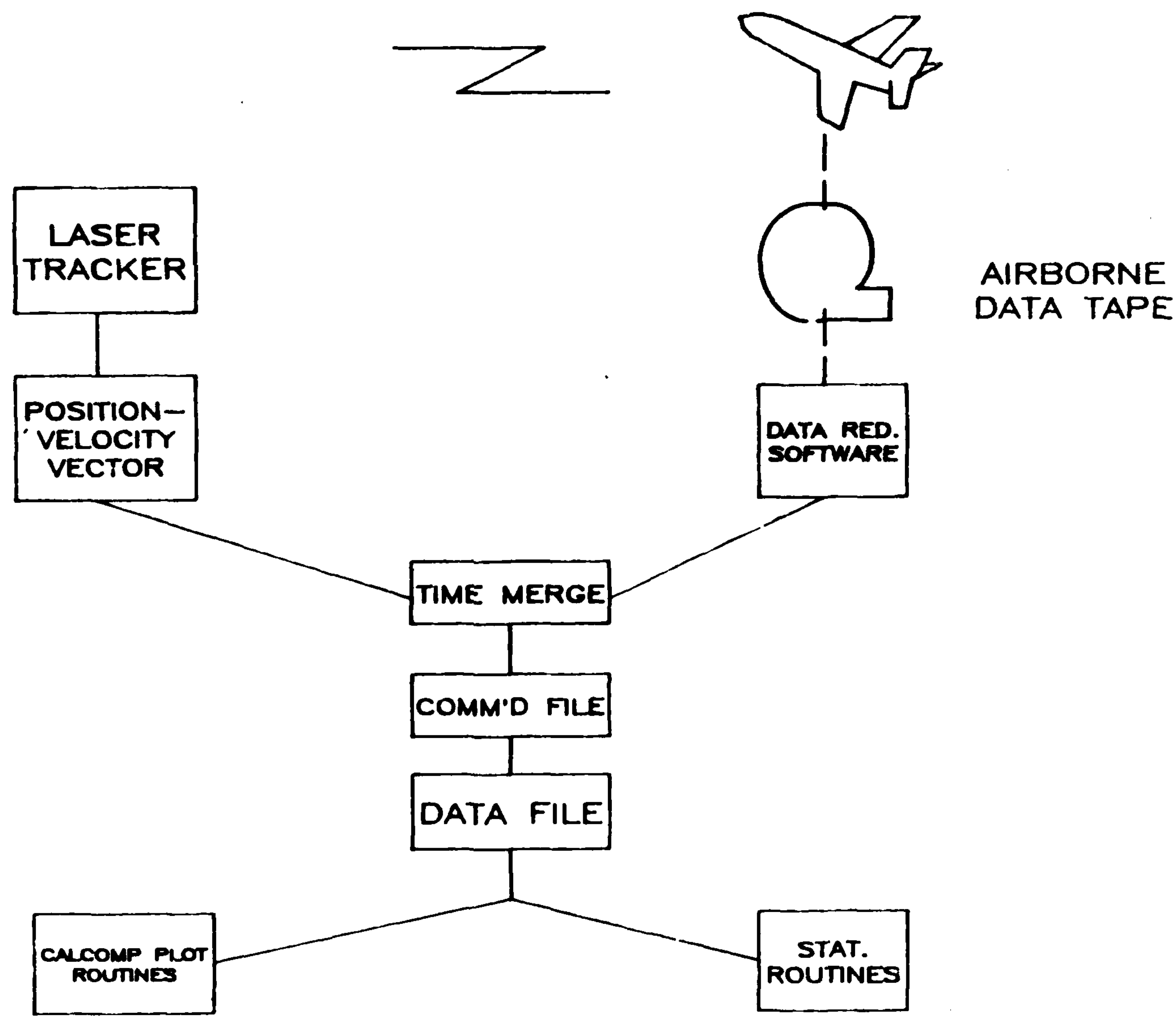


FIGURE 2. DATA REDUCTION PROCEDURES

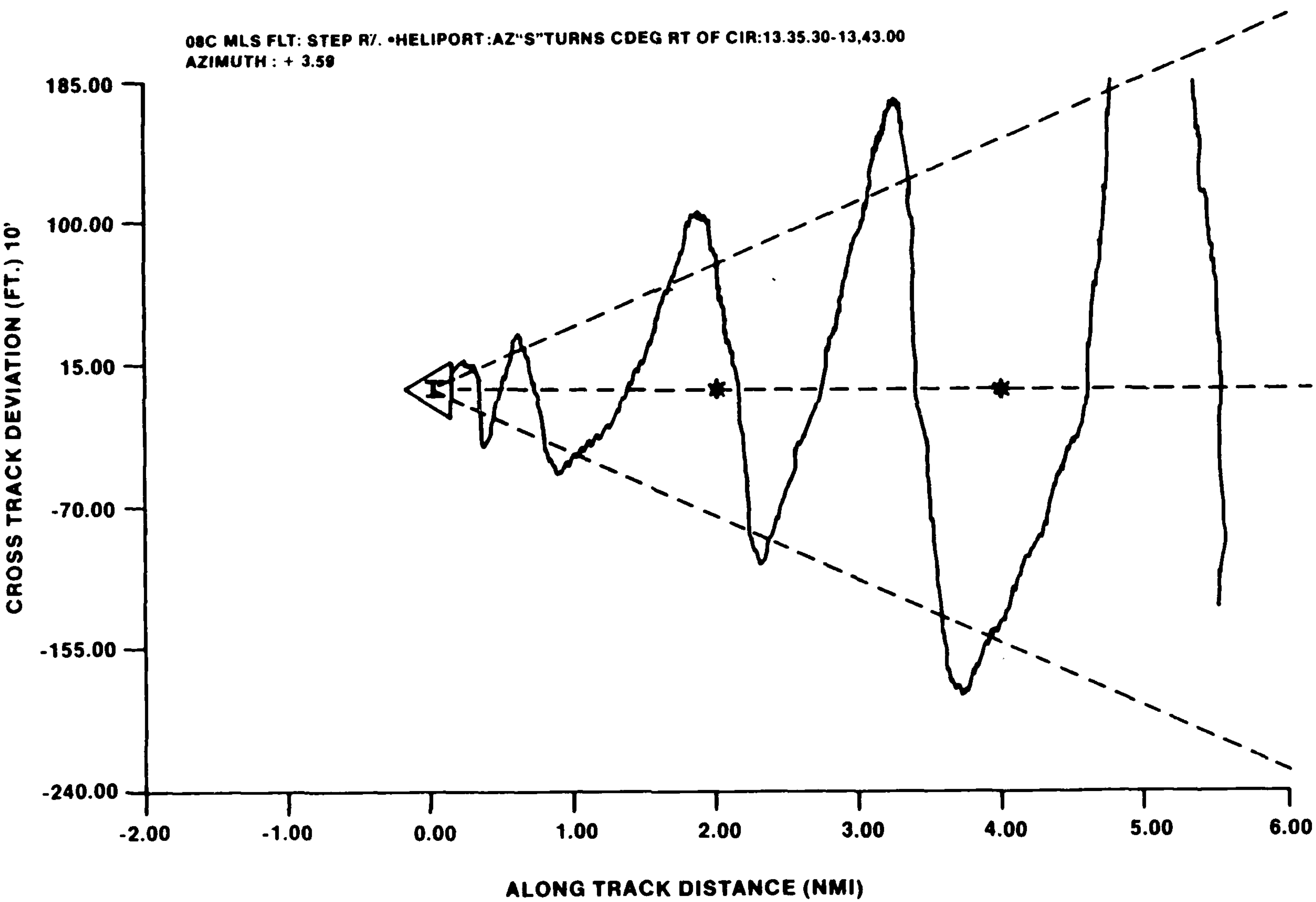


FIGURE 3. "S" PATTERN AZIMUTH COURSE WIDTH RESULTS

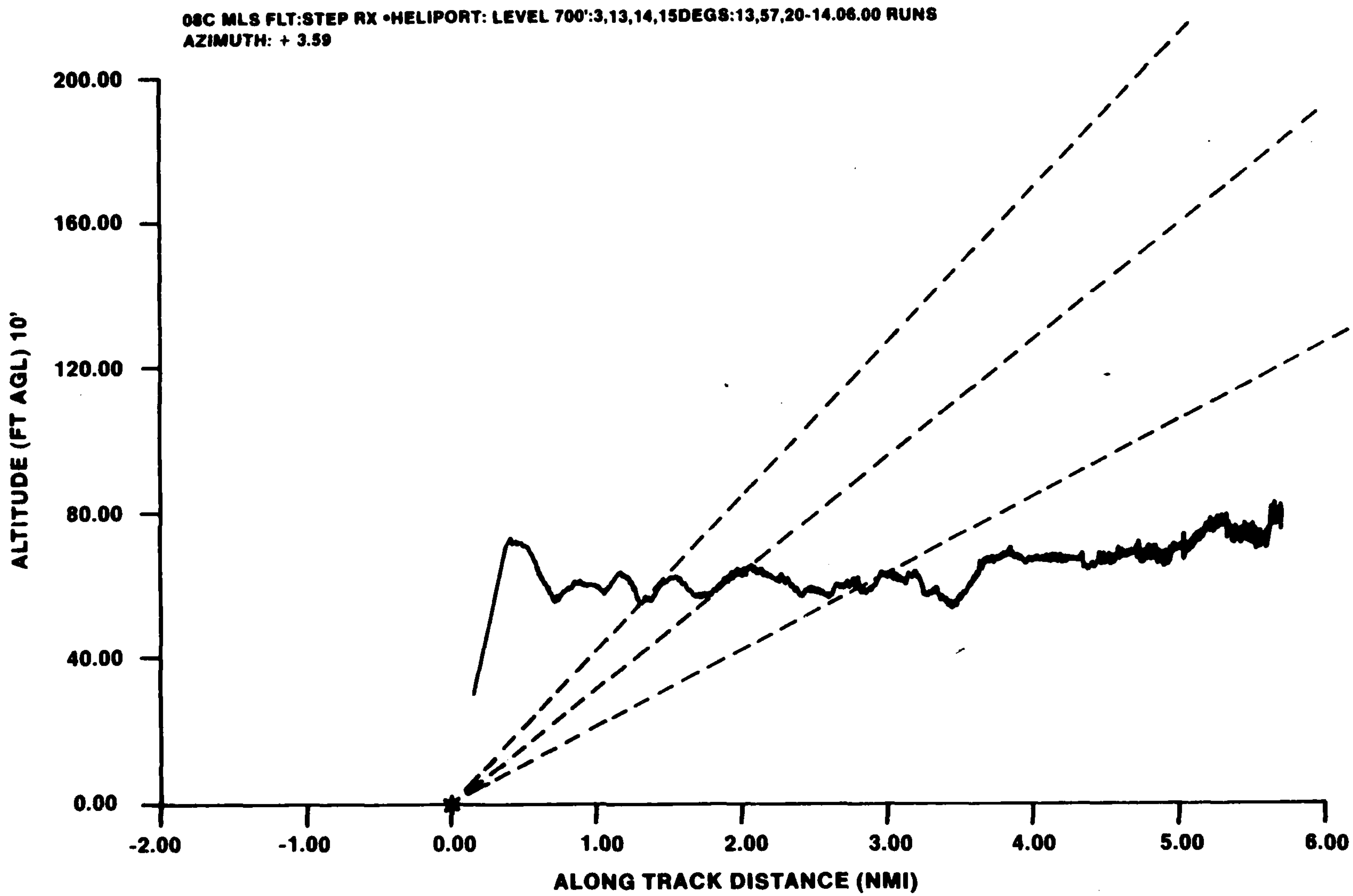


FIGURE 4. LEVEL FLIGHT ELEVATION COURSE WIDTH RESULTS

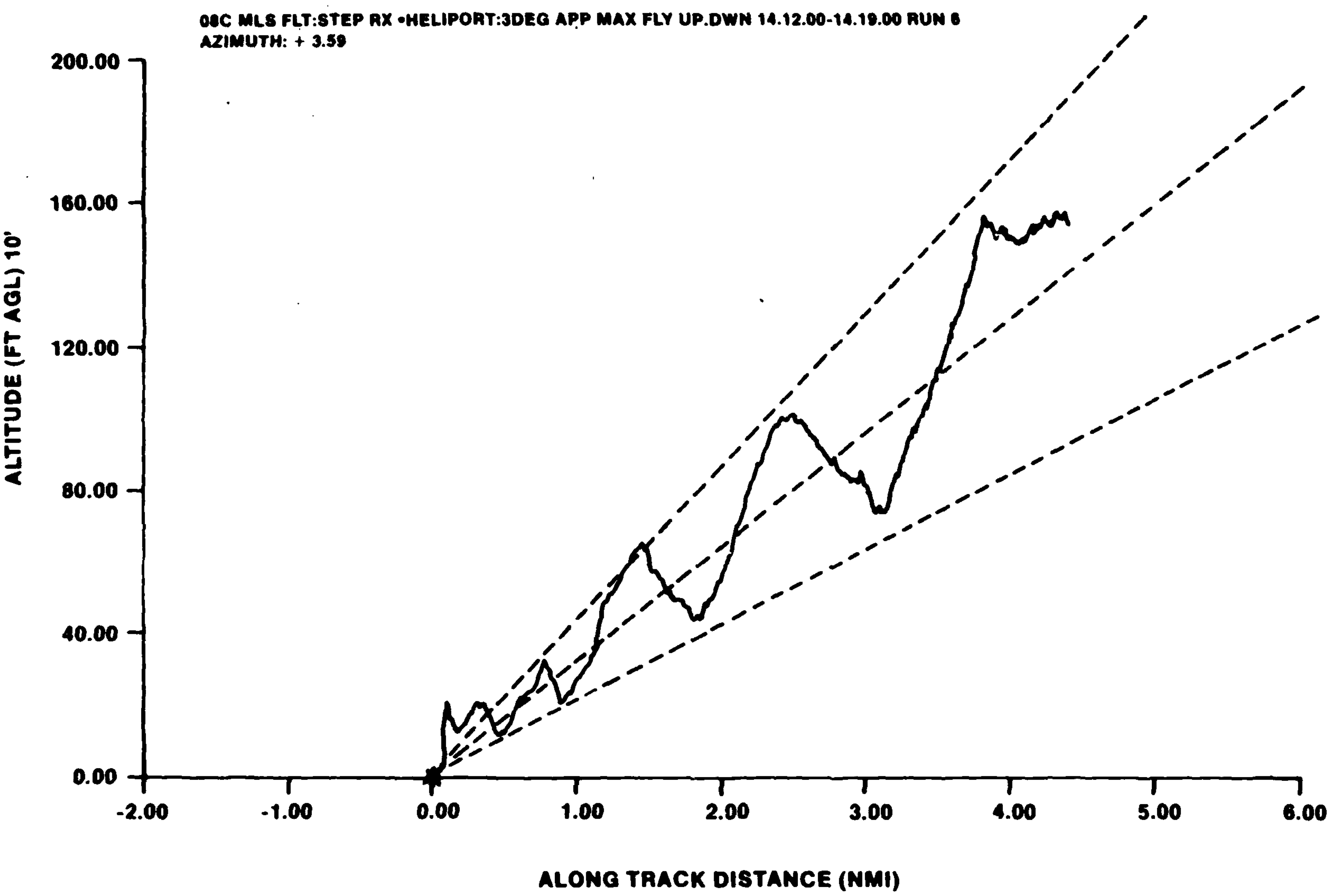


FIGURE 5. "S" PATTERN ELEVATION COURSE WIDTH RESULTS

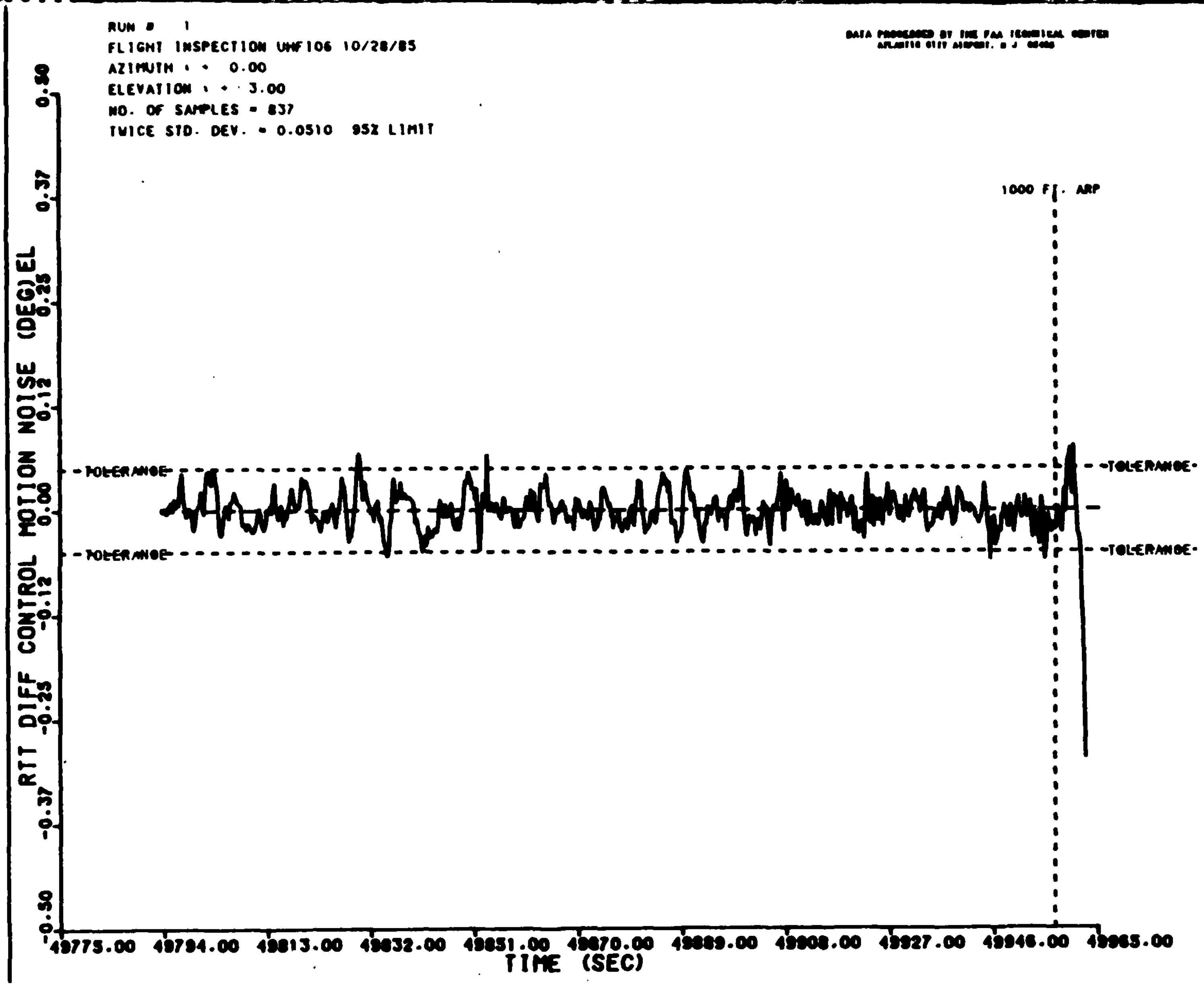


FIGURE 6. ELEVATION CMN RESULTS RUN 1, FLIGHT 6

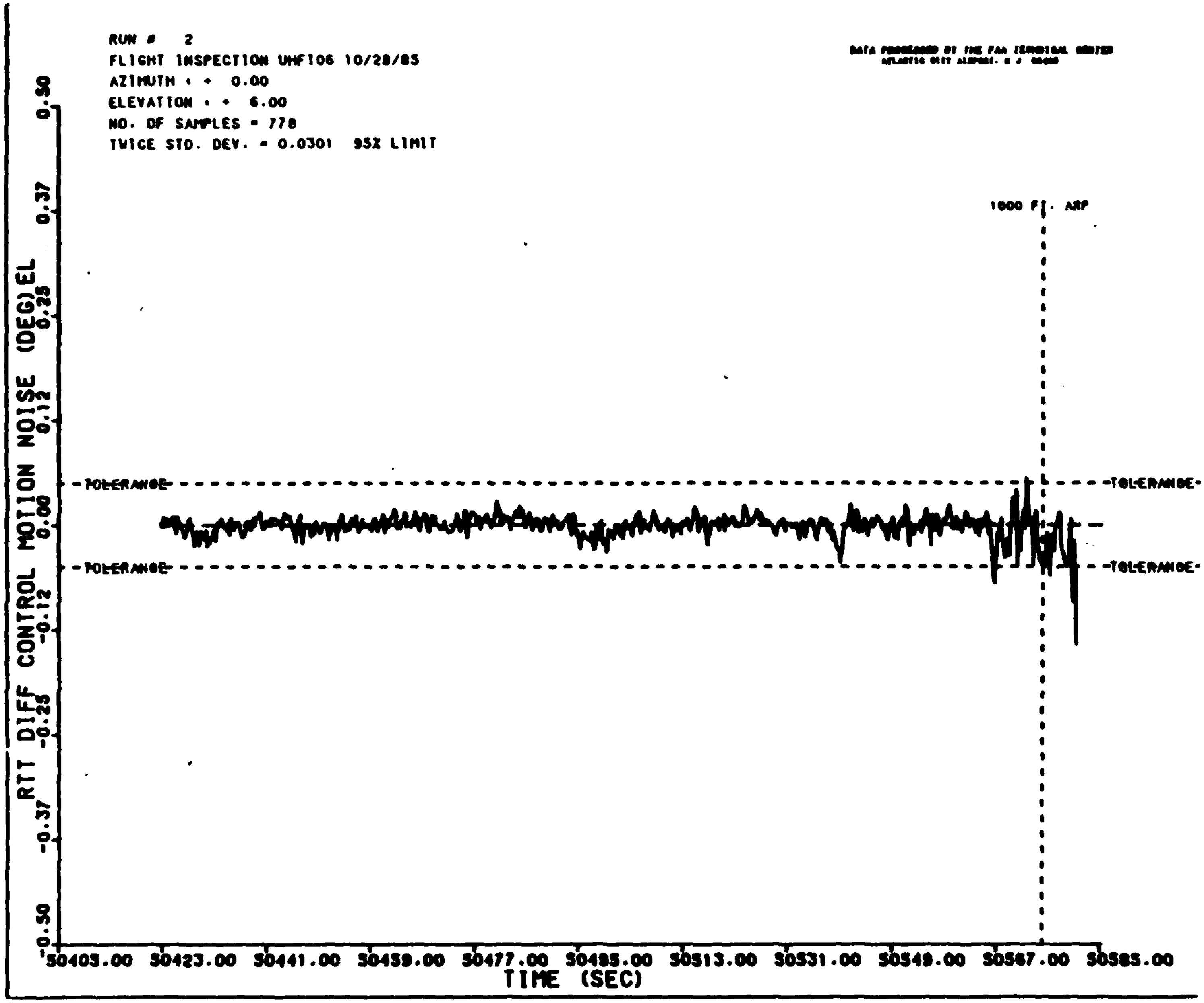


FIGURE 7. ELEVATION CMN RESULTS RUN 2, FLIGHT 6

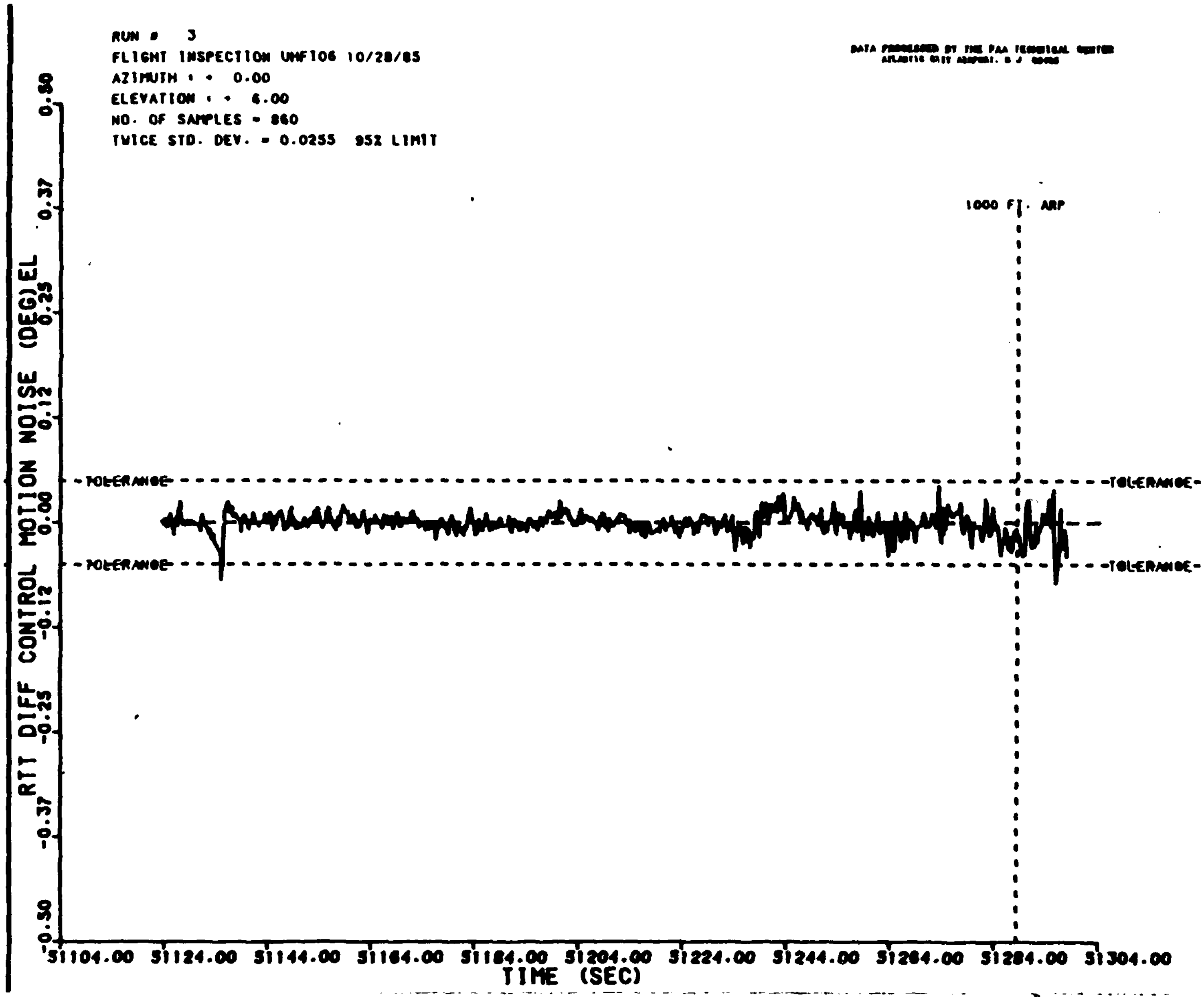


FIGURE 8. ELEVATION CMN RESULTS RUN 3, FLIGHT 6

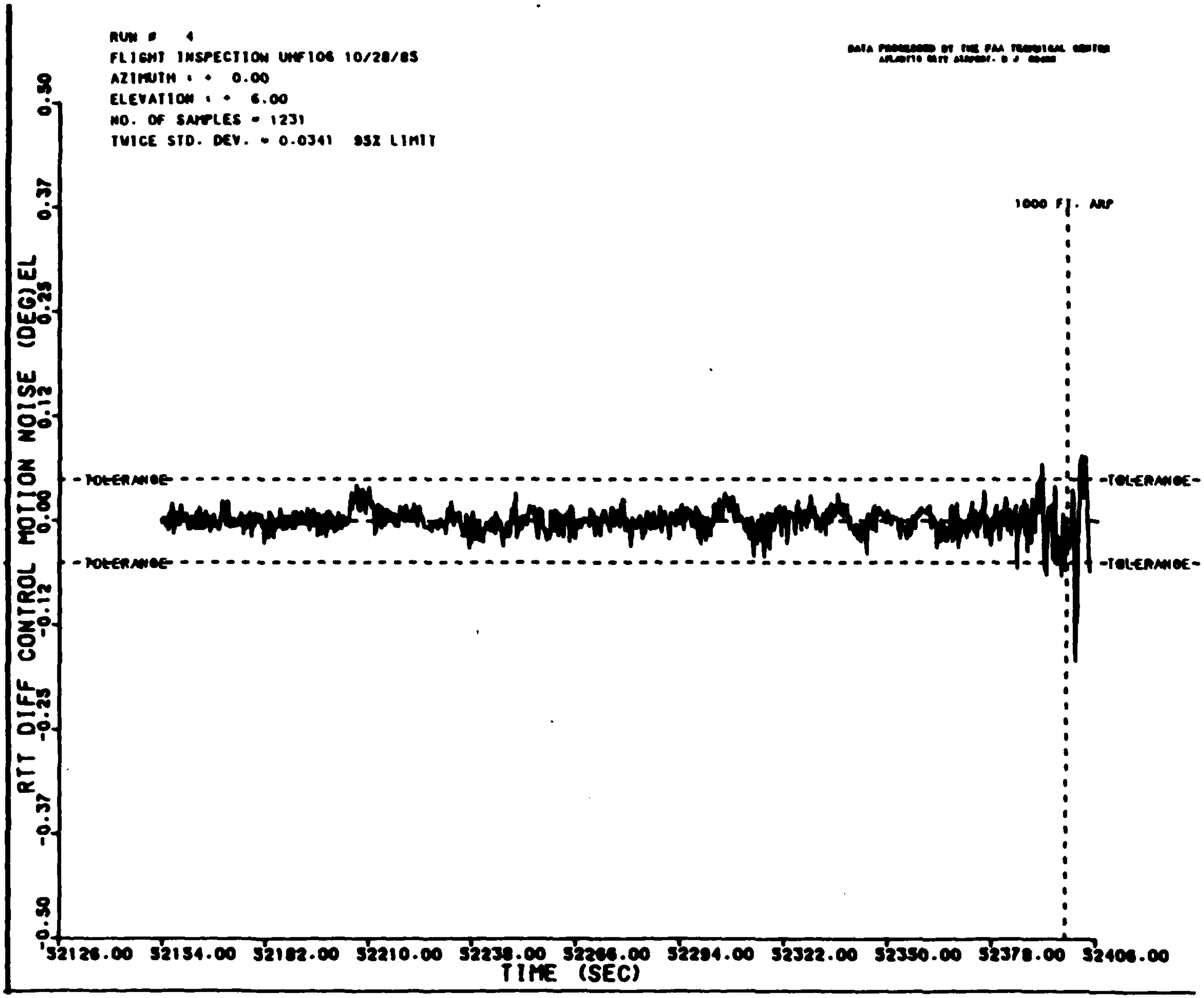


FIGURE 9. ELEVATION CMN RESULTS RUN 4, FLIGHT 6

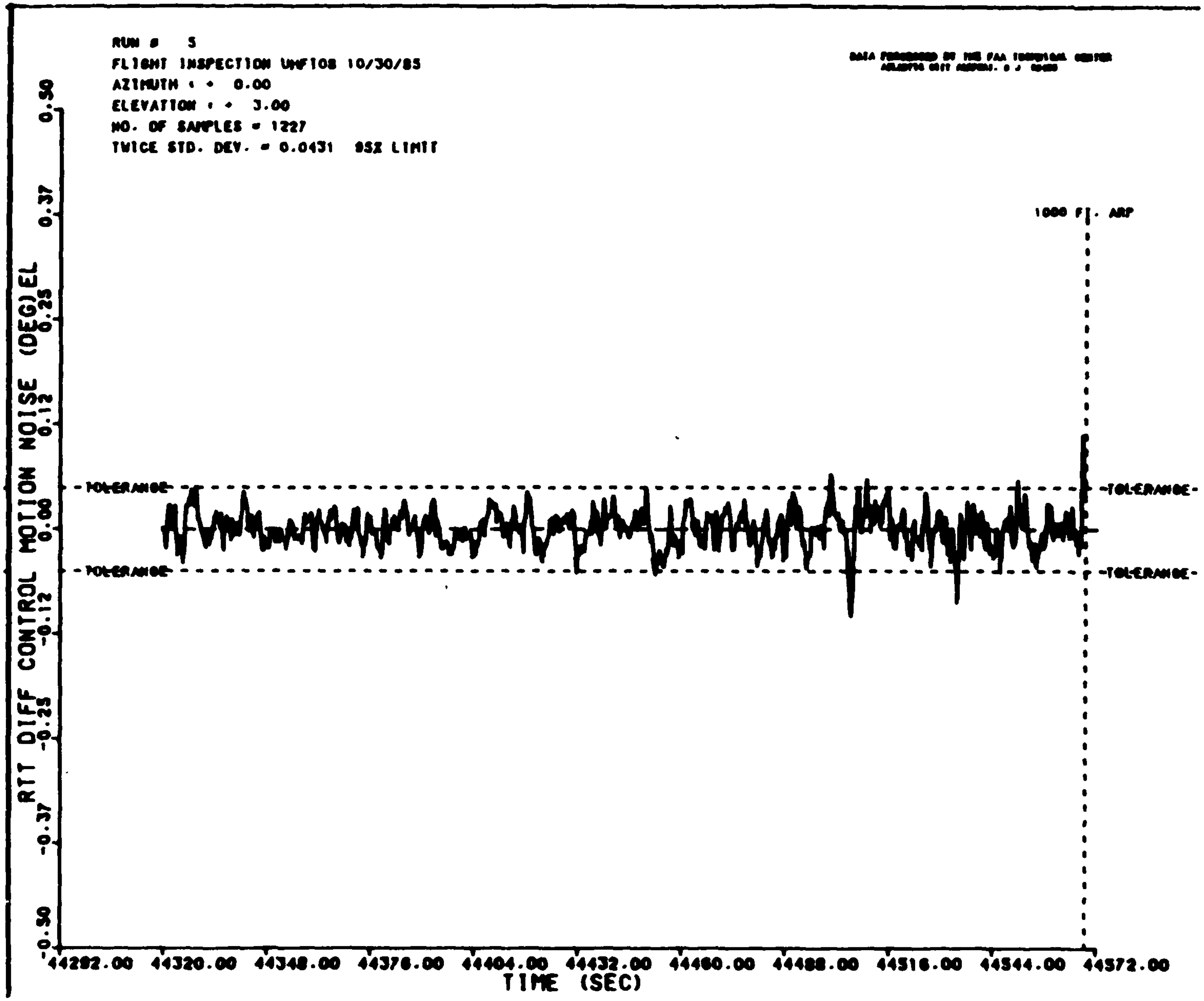


FIGURE 10. ELEVATION CMN RESULTS RUN 5, FLIGHT 8

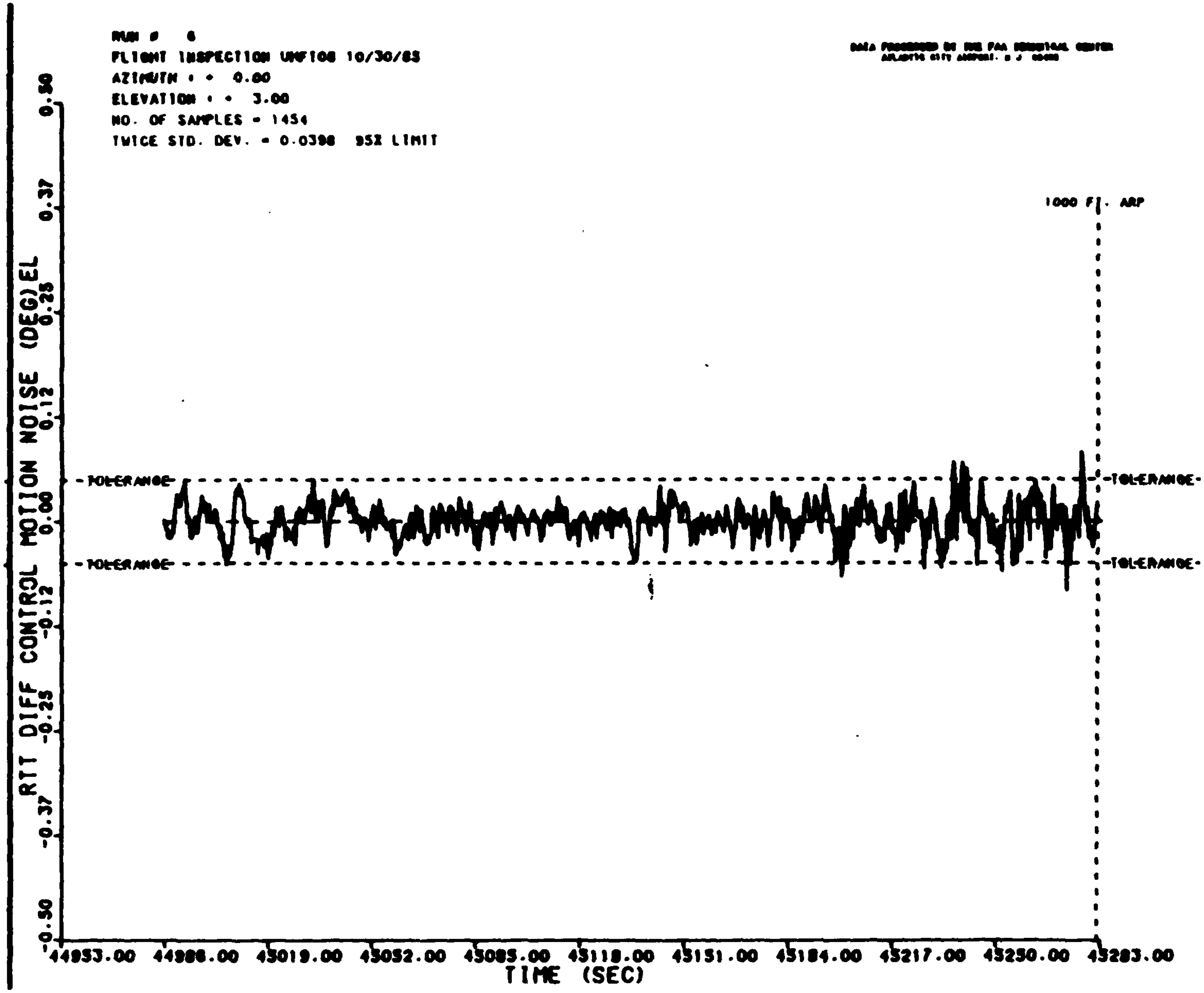


FIGURE 11. ELEVATION CMN RESULTS RUN 6, FLIGHT 8

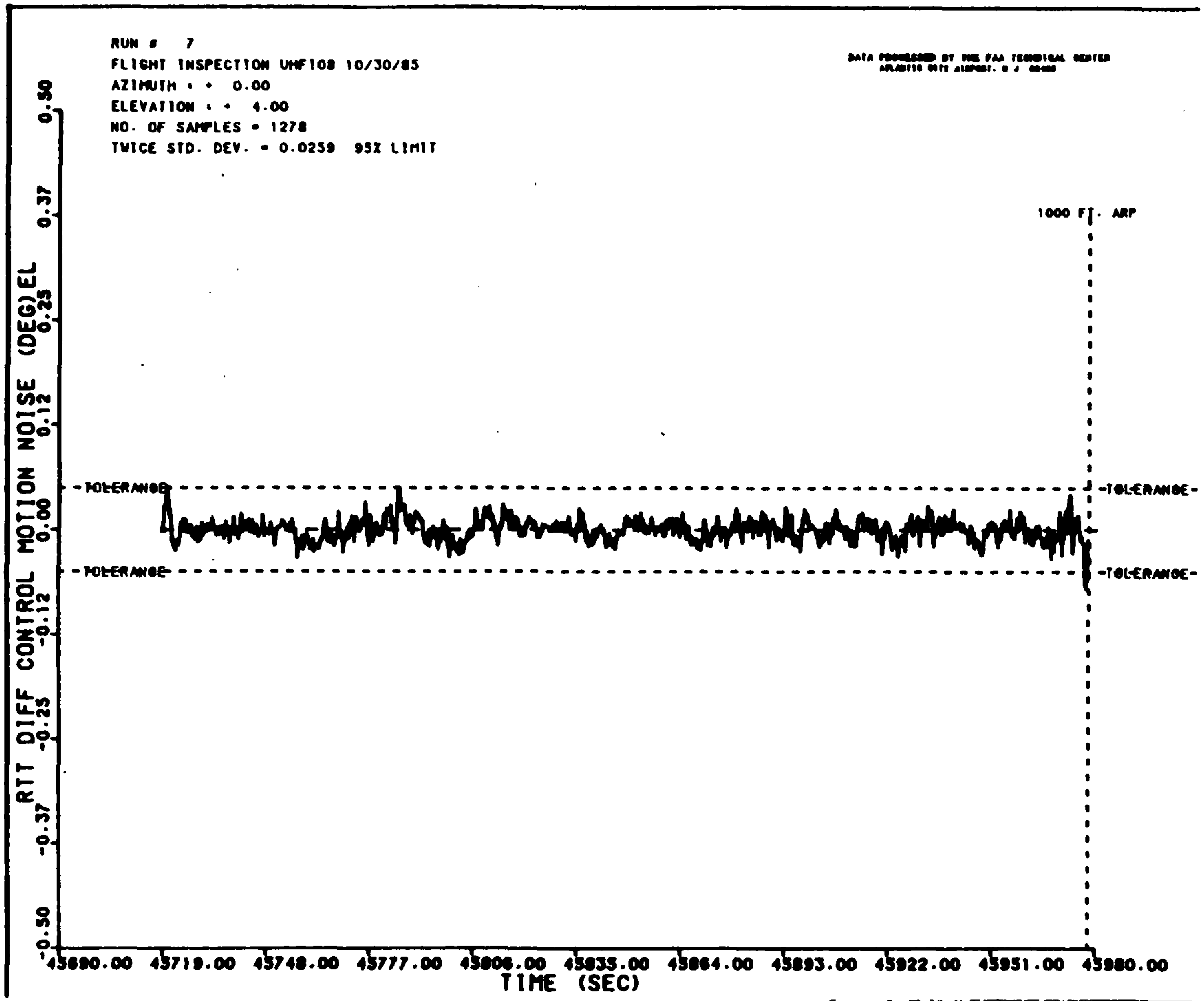


FIGURE 12. ELEVATION CMN RESULTS RUN 7, FLIGHT 8

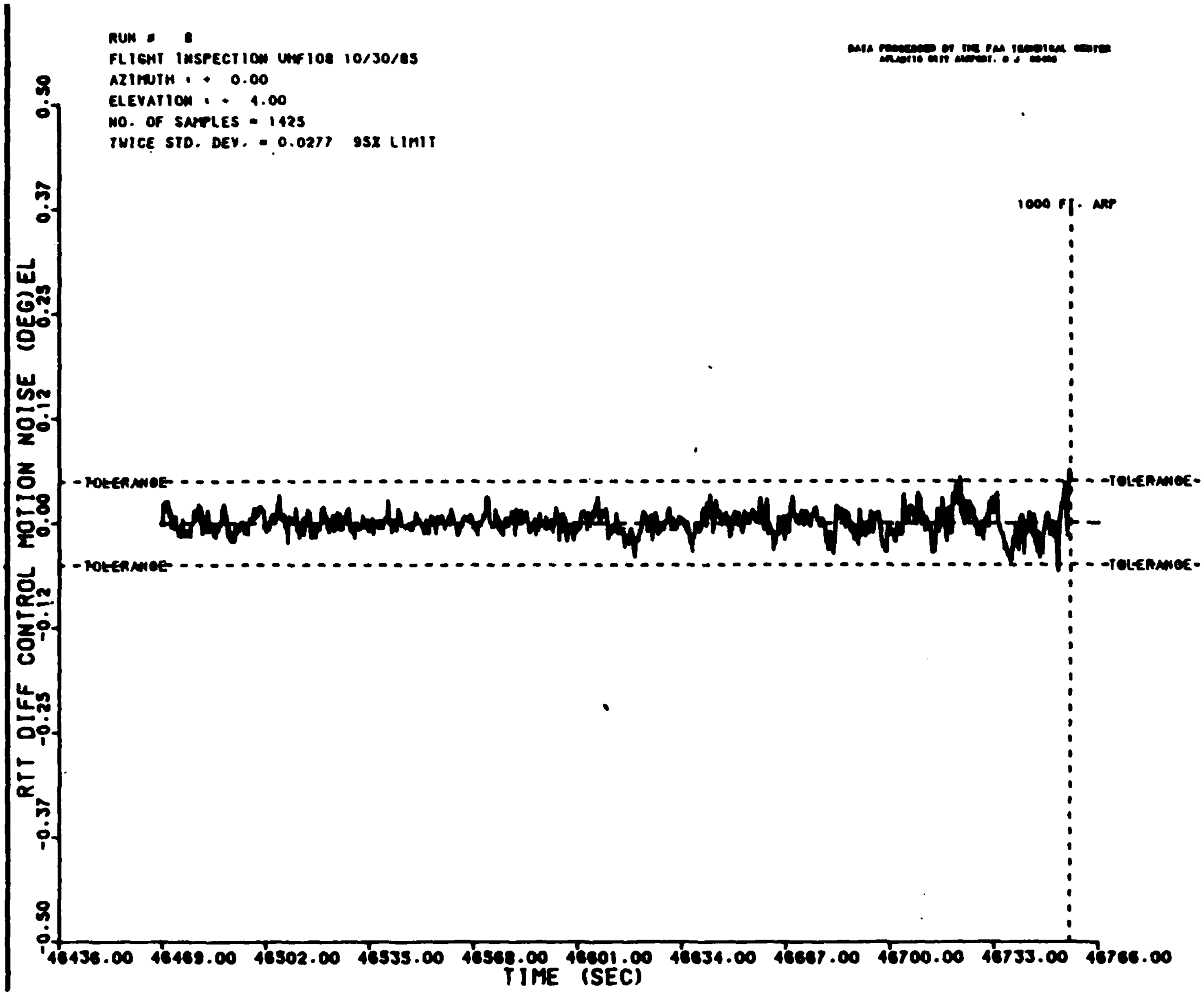


FIGURE 13. ELEVATION CMN RESULTS RUN 8, FLIGHT 8

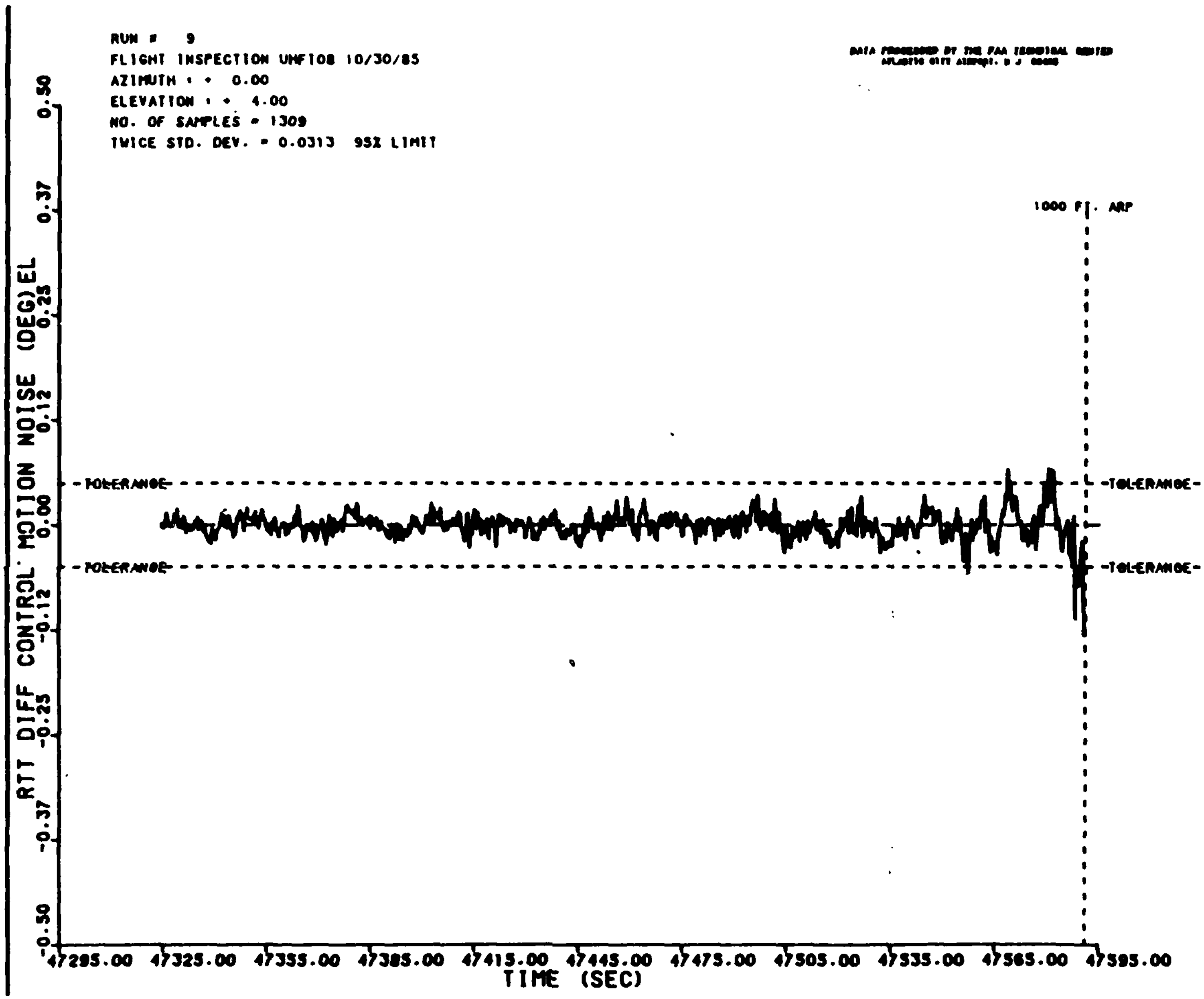


FIGURE 14. ELEVATION CMN RESULTS RUN 9, FLIGHT 8

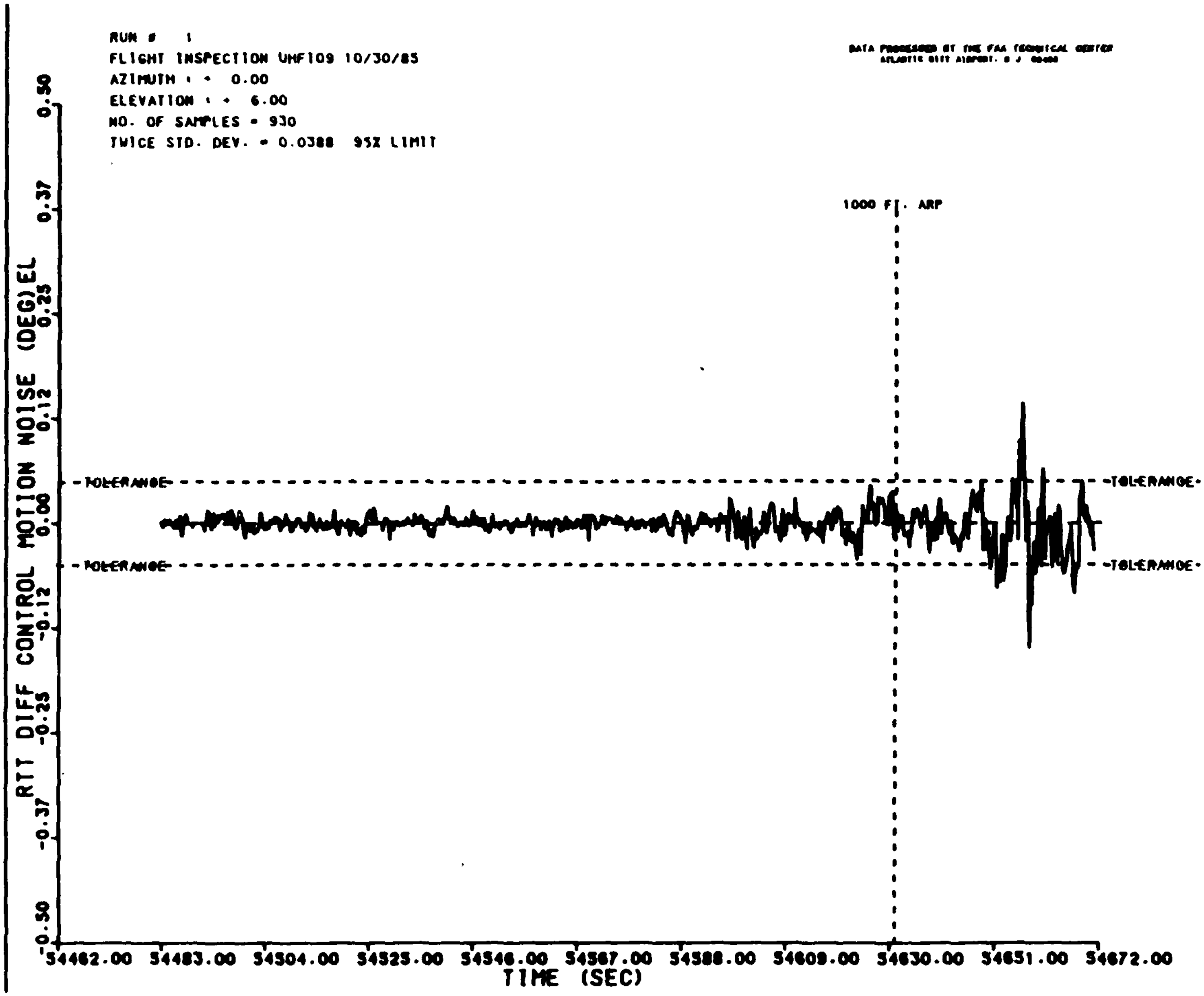


FIGURE 15. ELEVATION CMN RESULTS RUN 1, FLIGHT 9

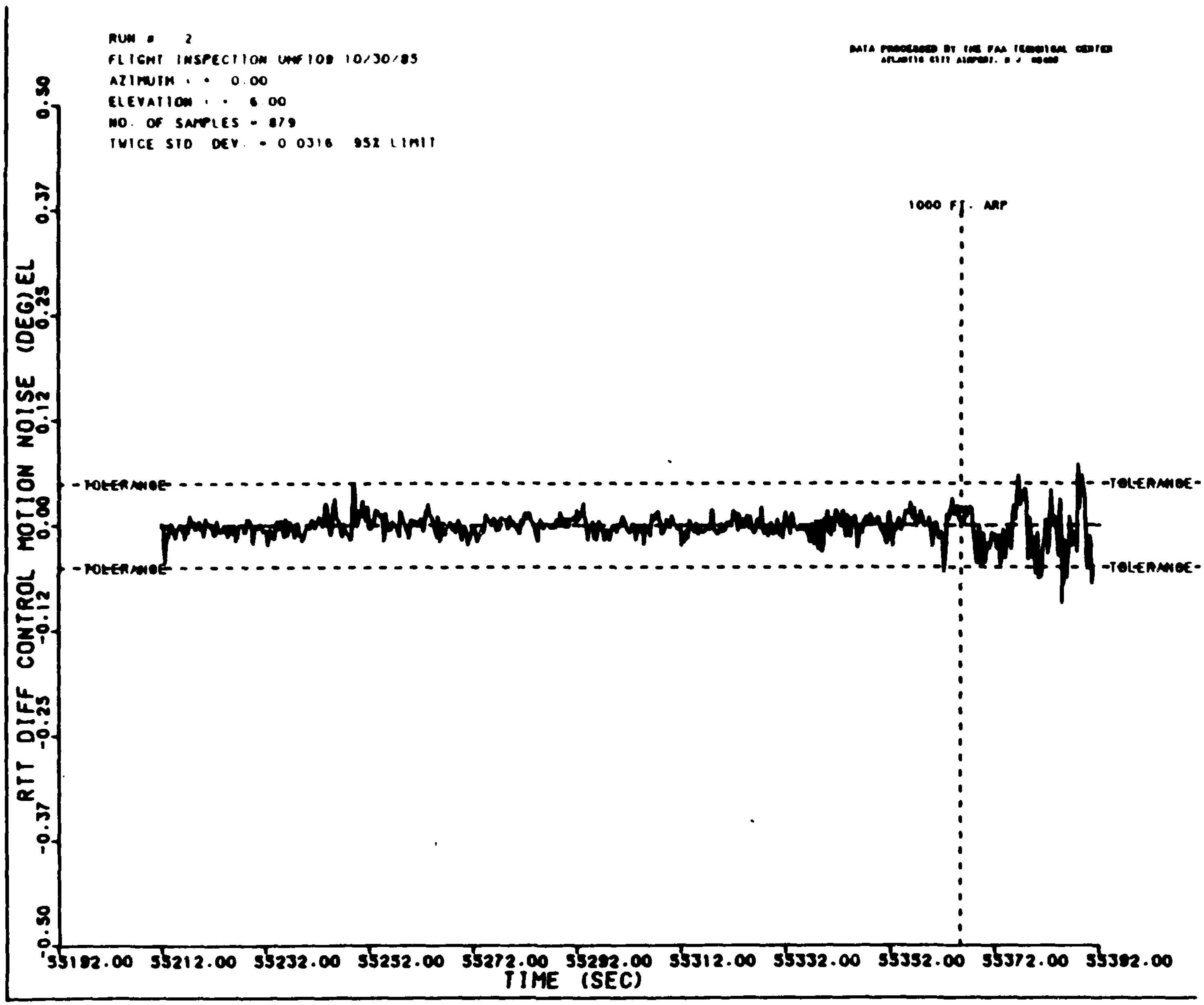
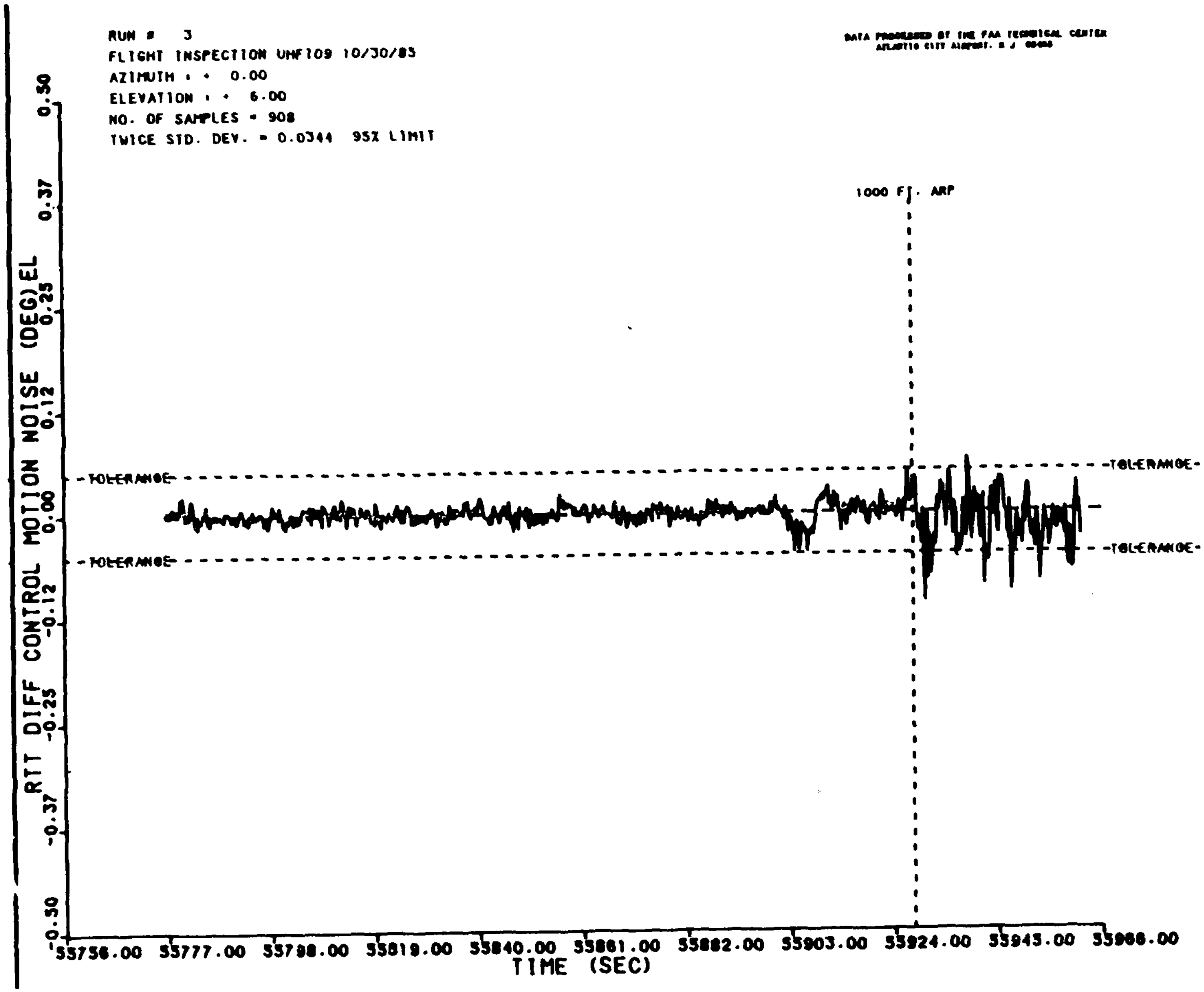


FIGURE 16. ELEVATION CMN RESULTS RUN 2, FLIGHT 9


RUN # 3
FLIGHT INSPECTION UMF109 10/30/85
AZIMUTH : + 0.00
ELEVATION : + 6.00
NO. OF SAMPLES = 908
TWICE STD. DEV. = 0.0344 95% LIMIT
DATA PROCESSED BY THE FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT, N.J. 08405
1000 FT. ARP
TOLERANCE
TOLERANCE
TOLERANCE
TOLERANCE
RTT DIFF CONTROL MOTION NOISE (DEG)EL
0.50
0.37
0.25
0.12
0.00
-0.12
-0.25
-0.37
-0.50
55756.00
55777.00
55798.00
55819.00
55840.00
55861.00
55882.00
55903.00
55924.00
55945.00
55966.00
TIME (SEC)

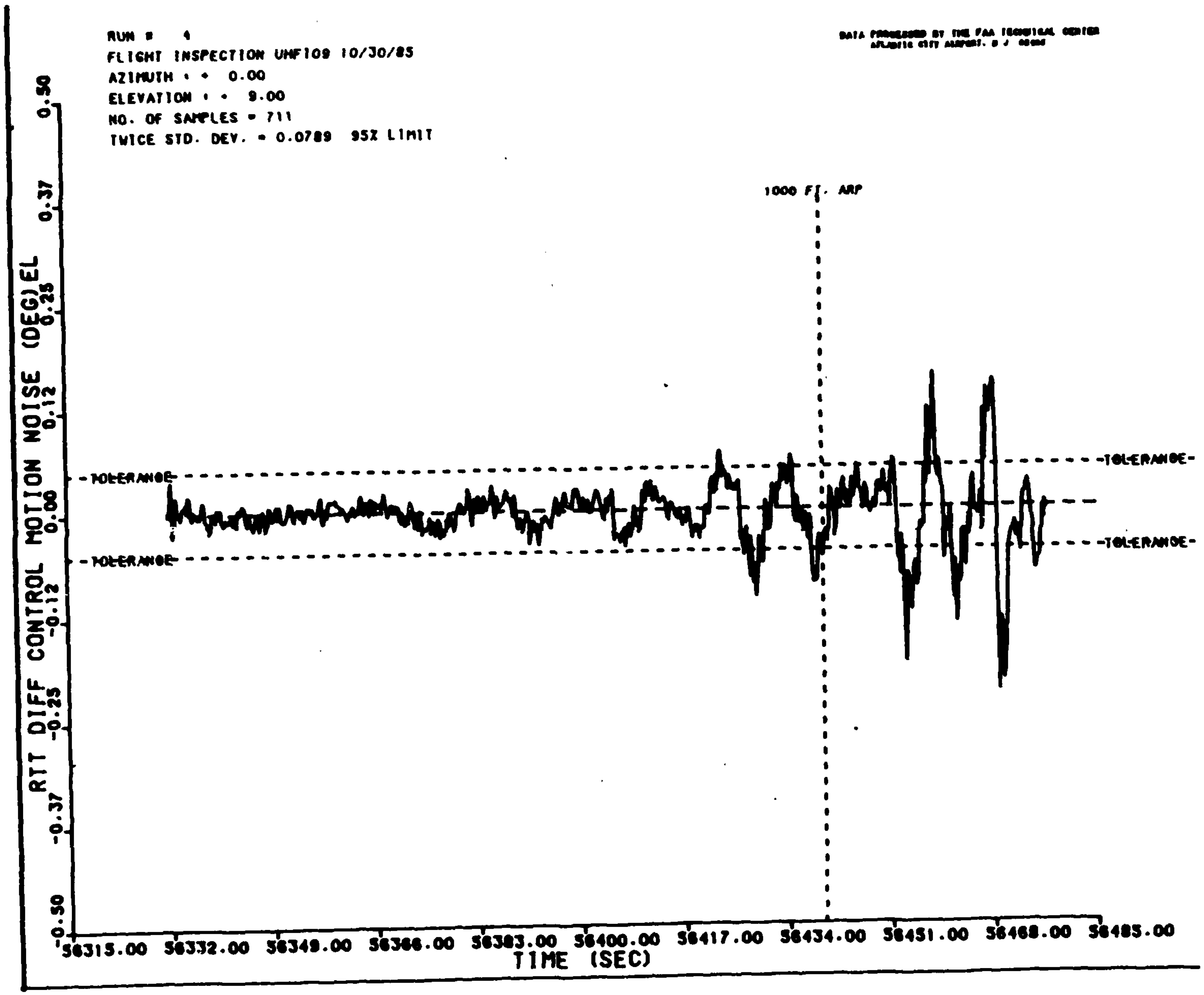


FIGURE 18. ELEVATION CMN RESULTS RUN 4, FLIGHT 9

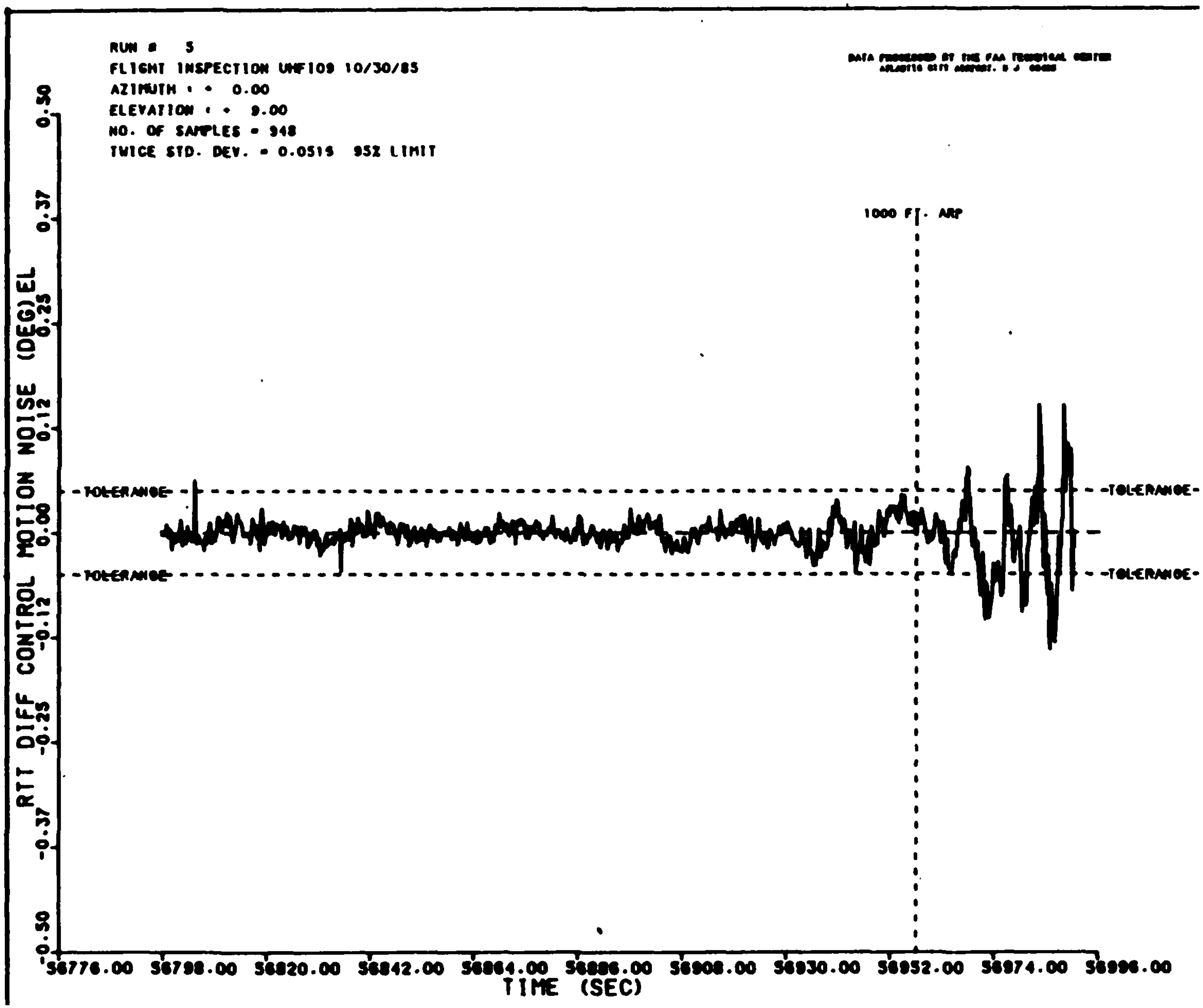


FIGURE 19. ELEVATION CMN RESULTS RUN 5, FLIGHT 9

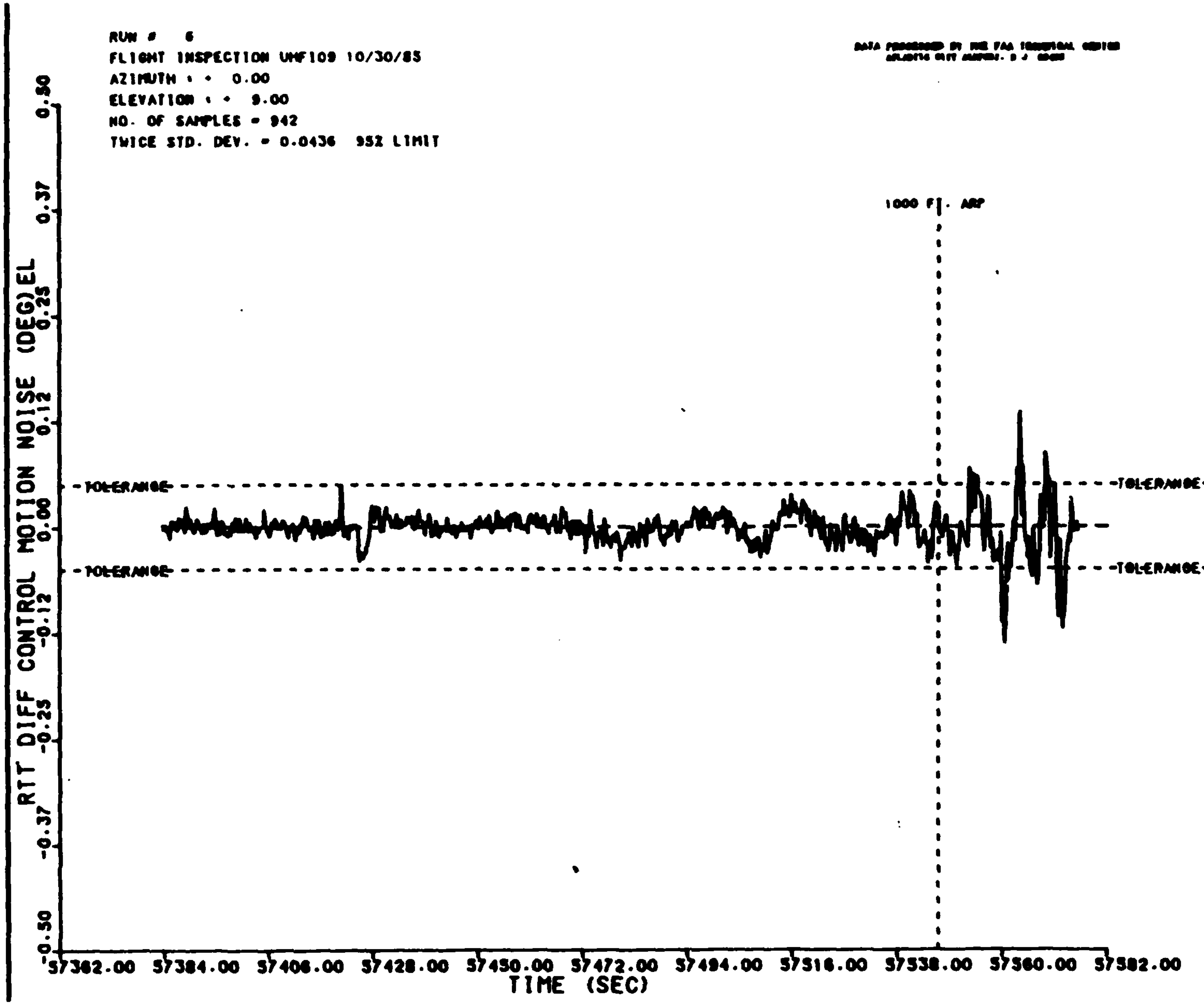


FIGURE 20. ELEVATION CMN RESULTS RUN 6, FLIGHT 9

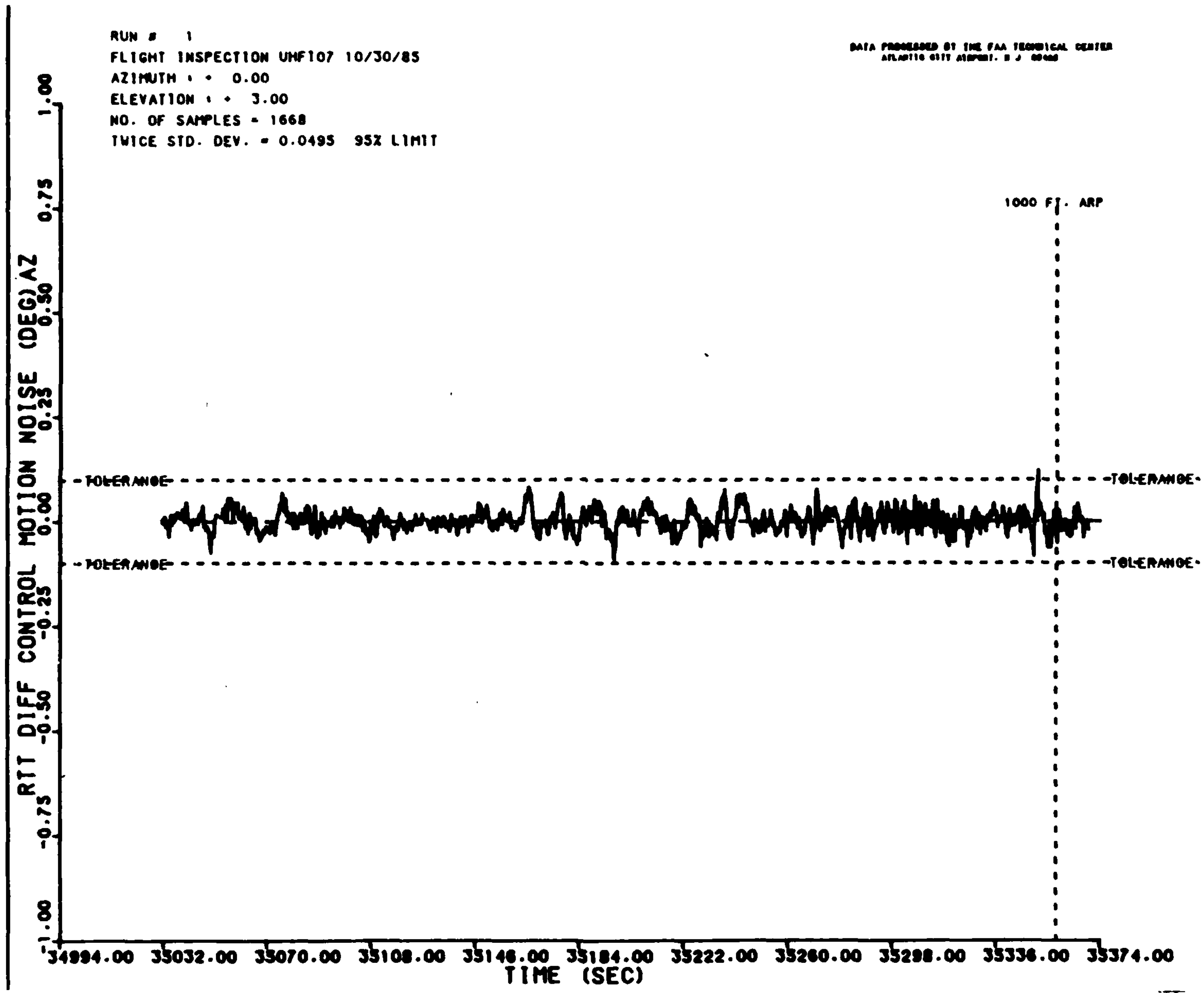


FIGURE 21. AZIMUTH OMN RESULTS RUN 1, FLIGHT 7

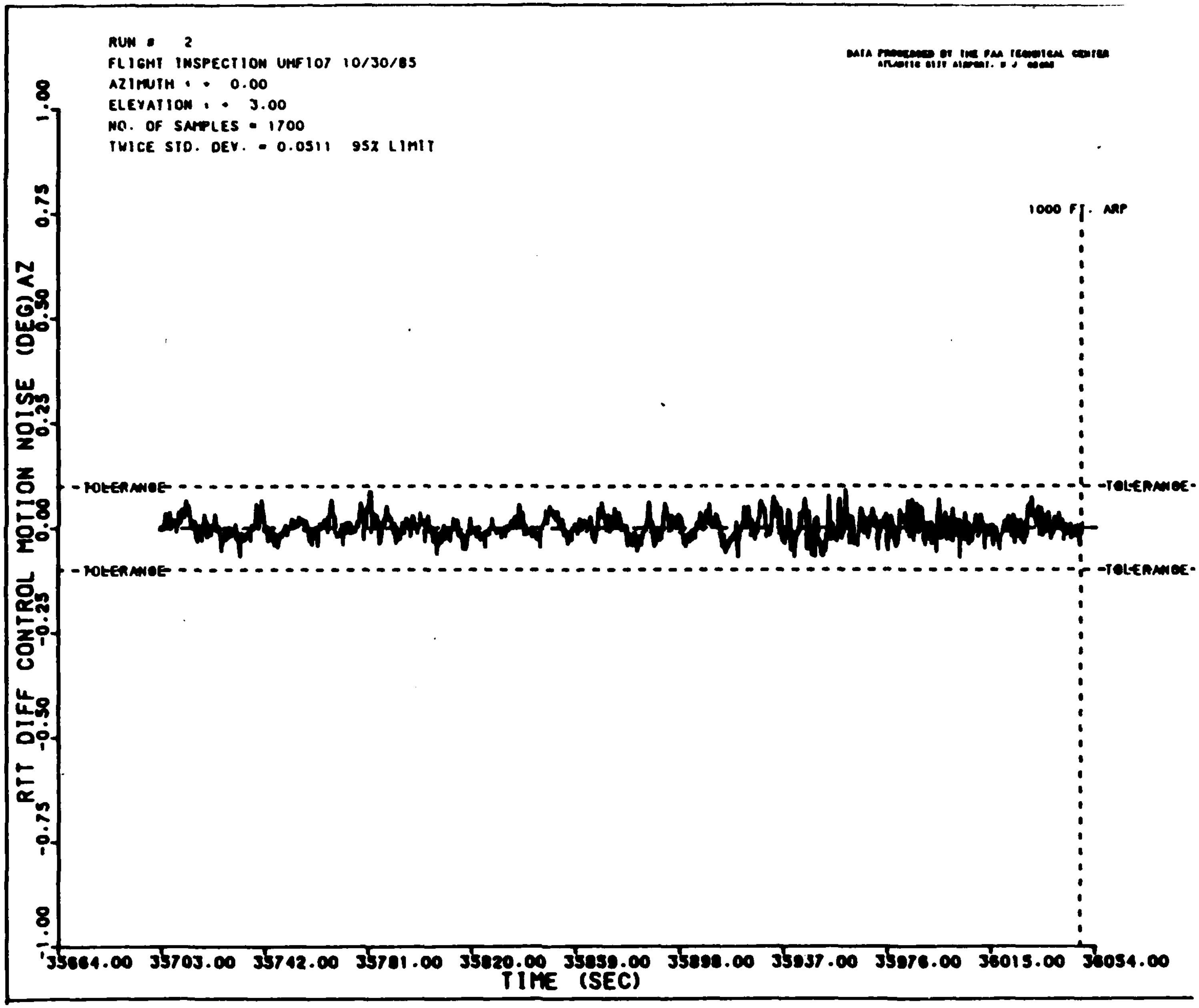


FIGURE 22. AZIMUTH CMN RESULTS RUN 2, FLIGHT 7

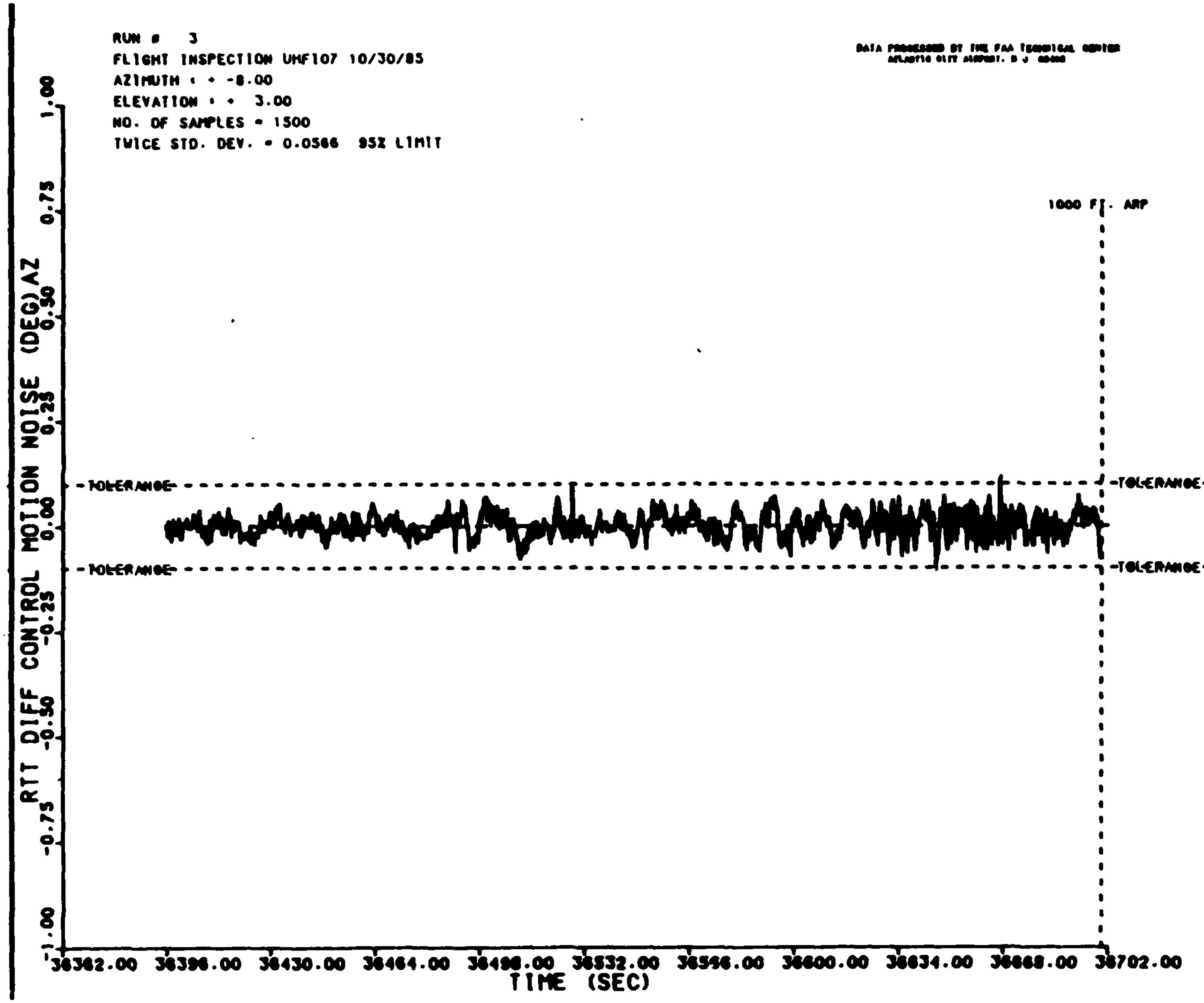


FIGURE 23. AZIMUTH CMN RESULTS RUN 3, FLIGHT 7

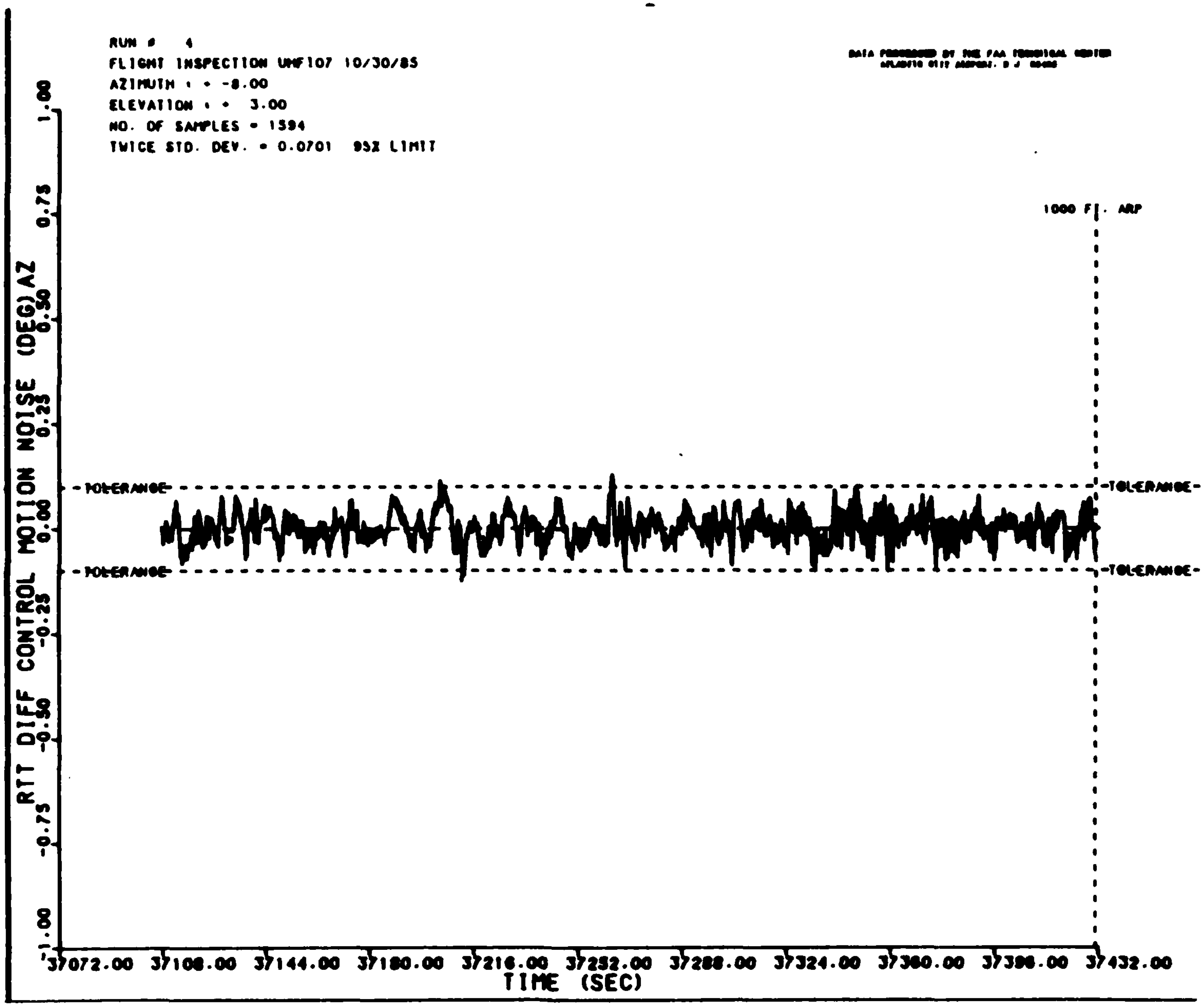


FIGURE 24. AZIMUTH CMN RESULTS RUN 4, FLIGHT 7

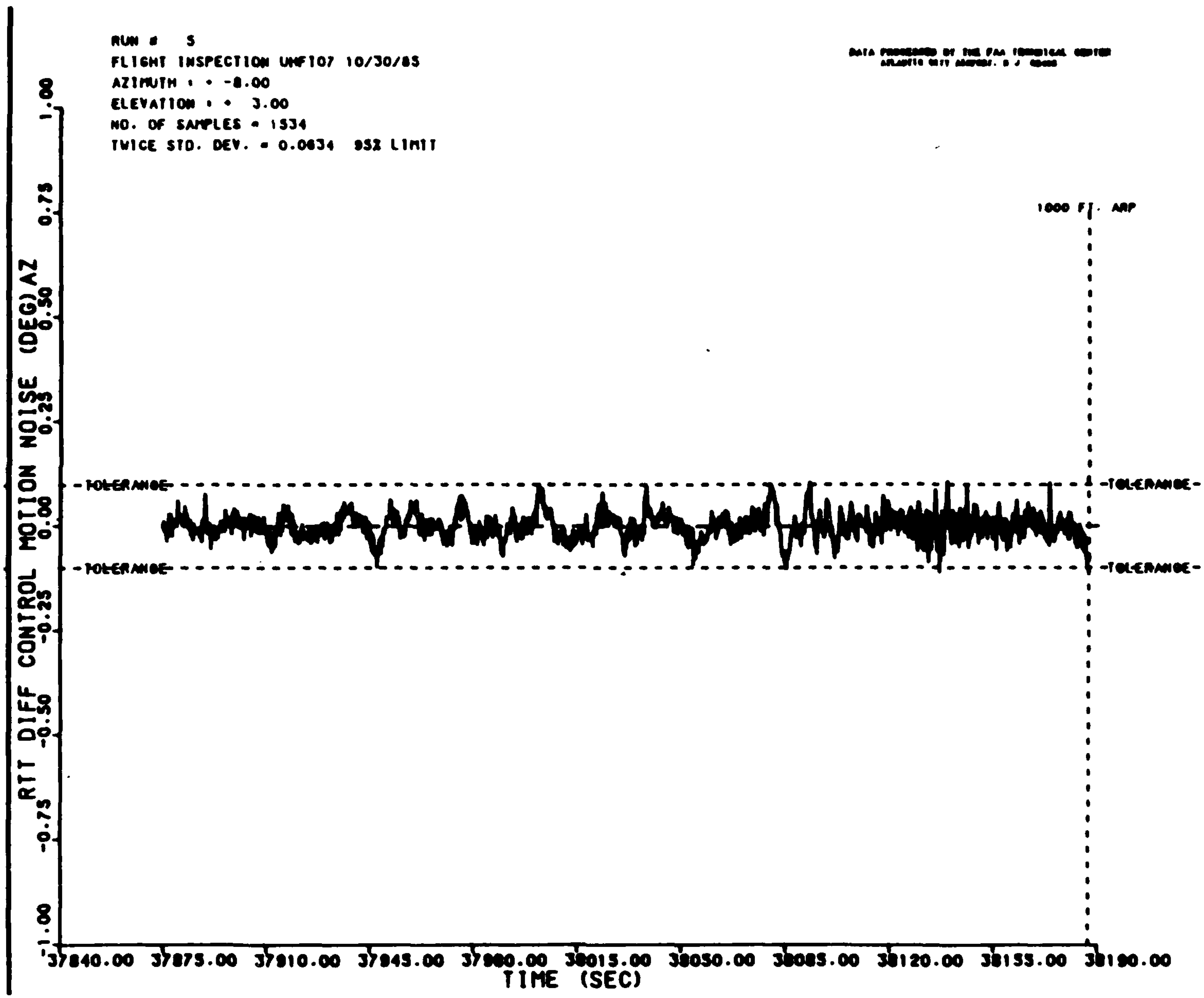


FIGURE 25. AZIMUTH CMN RESULTS RUN 5, FLIGHT 7

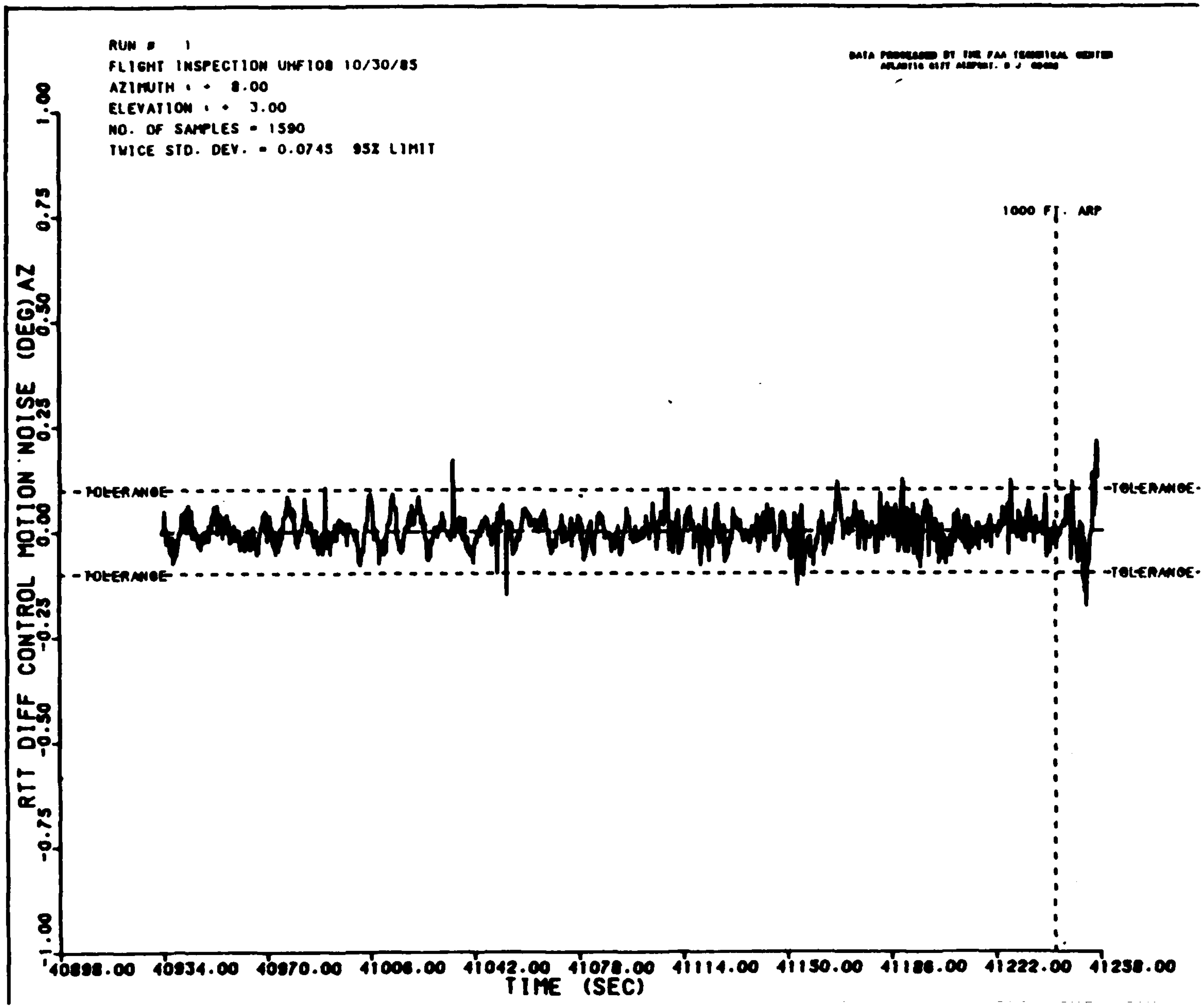


FIGURE 26. AZIMUTH CMN RESULTS RUN 1, FLIGHT 8

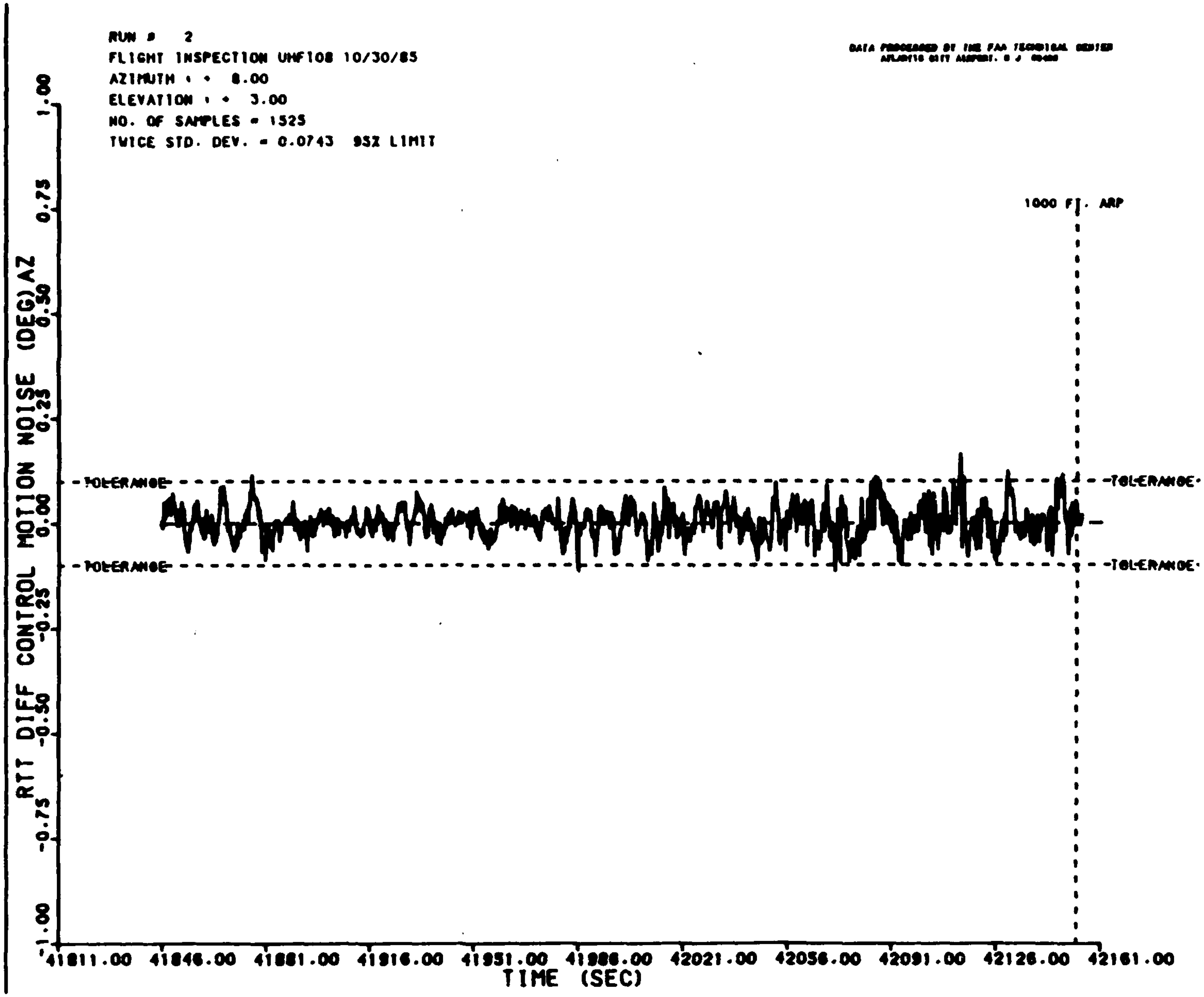


FIGURE 27. AZIMUTH CMN RESULTS RUN 2, FLIGHT 8

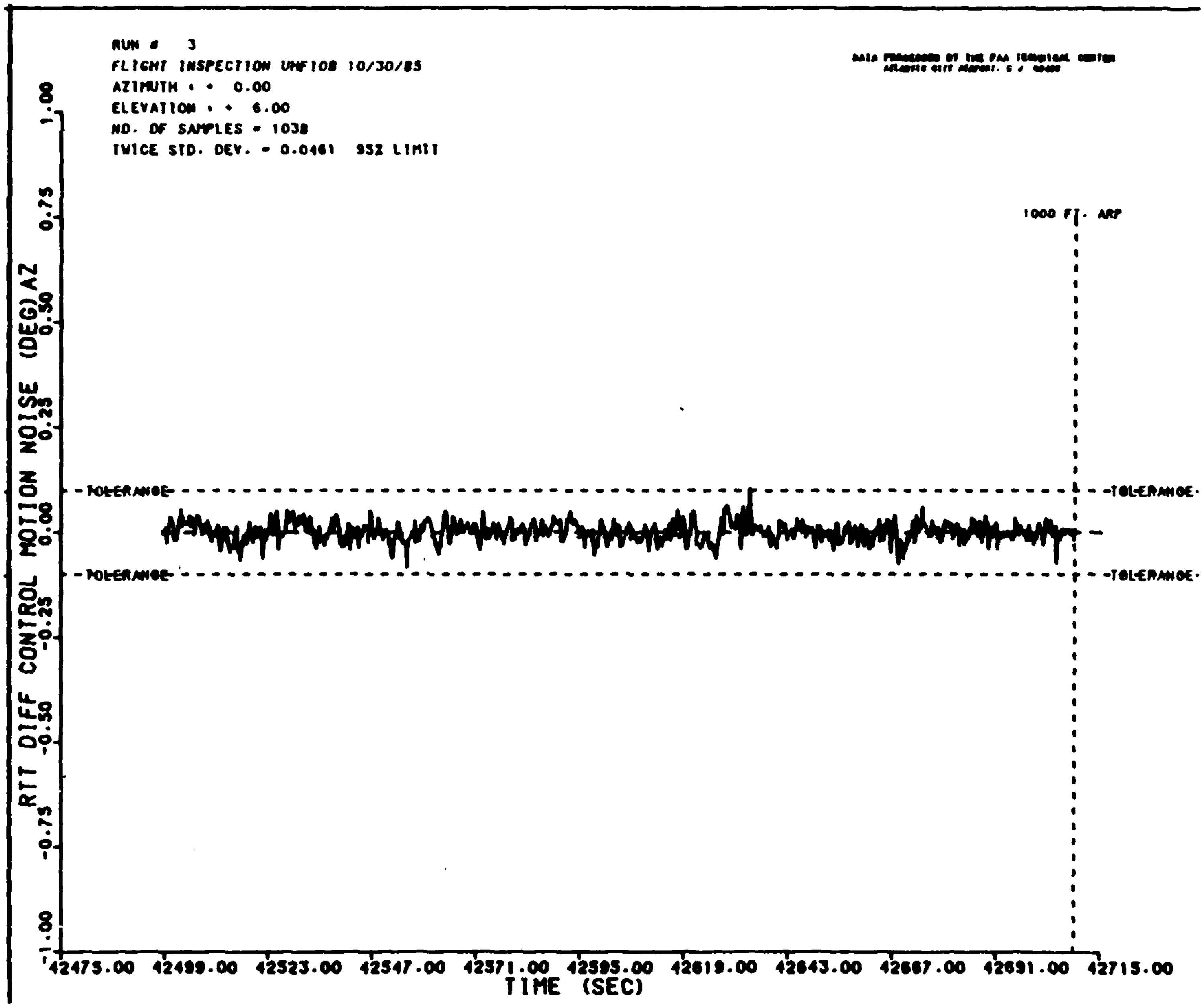


FIGURE 28. AZIMUTH CMN RESULTS RUN 3, FLIGHT 8

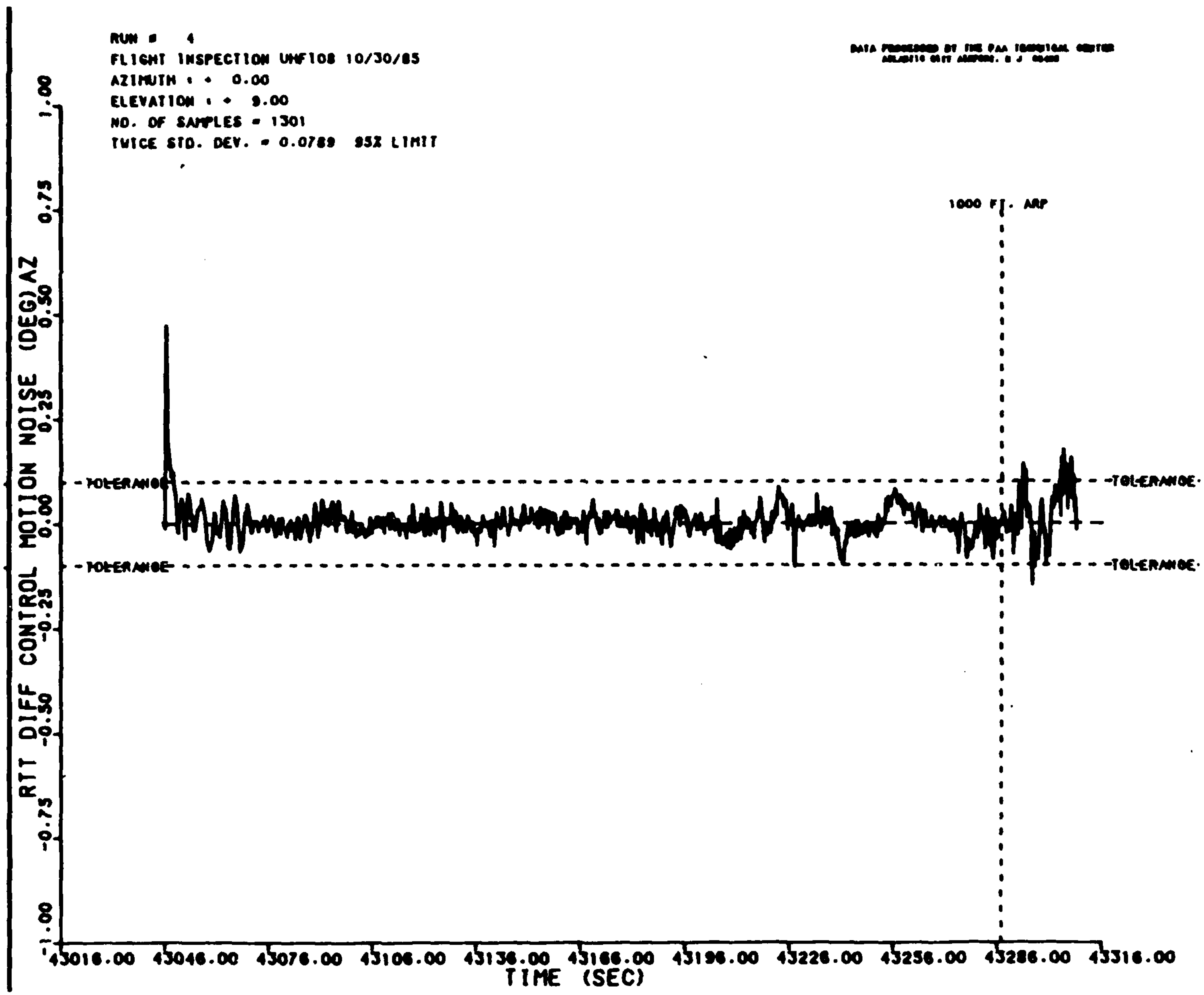


FIGURE 29. AZIMUTH CMN RESULTS RUN 4, FLIGHT 8

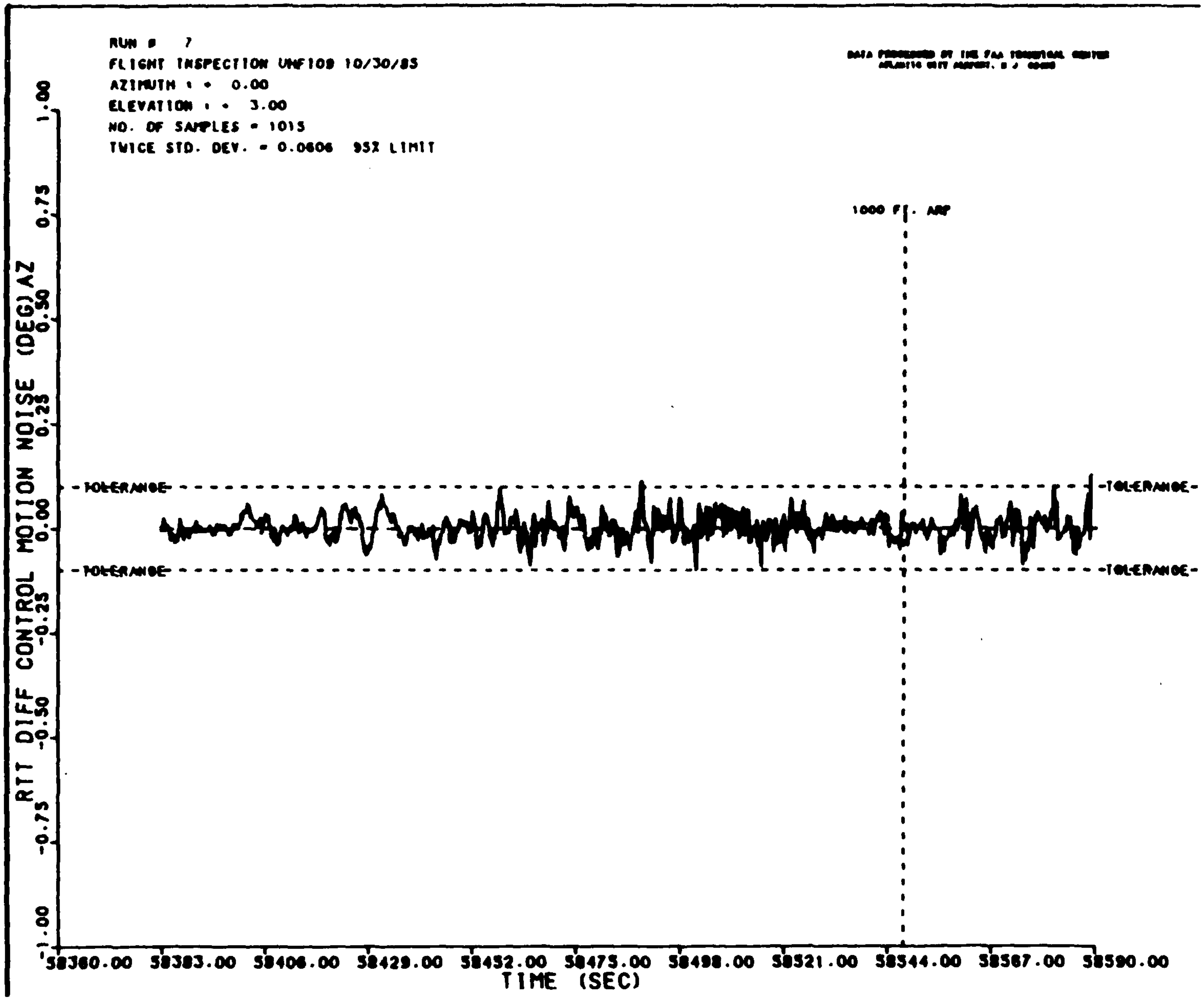


FIGURE 30. AZIMUTH CMN RESULTS RUN 7, FLIGHT 9

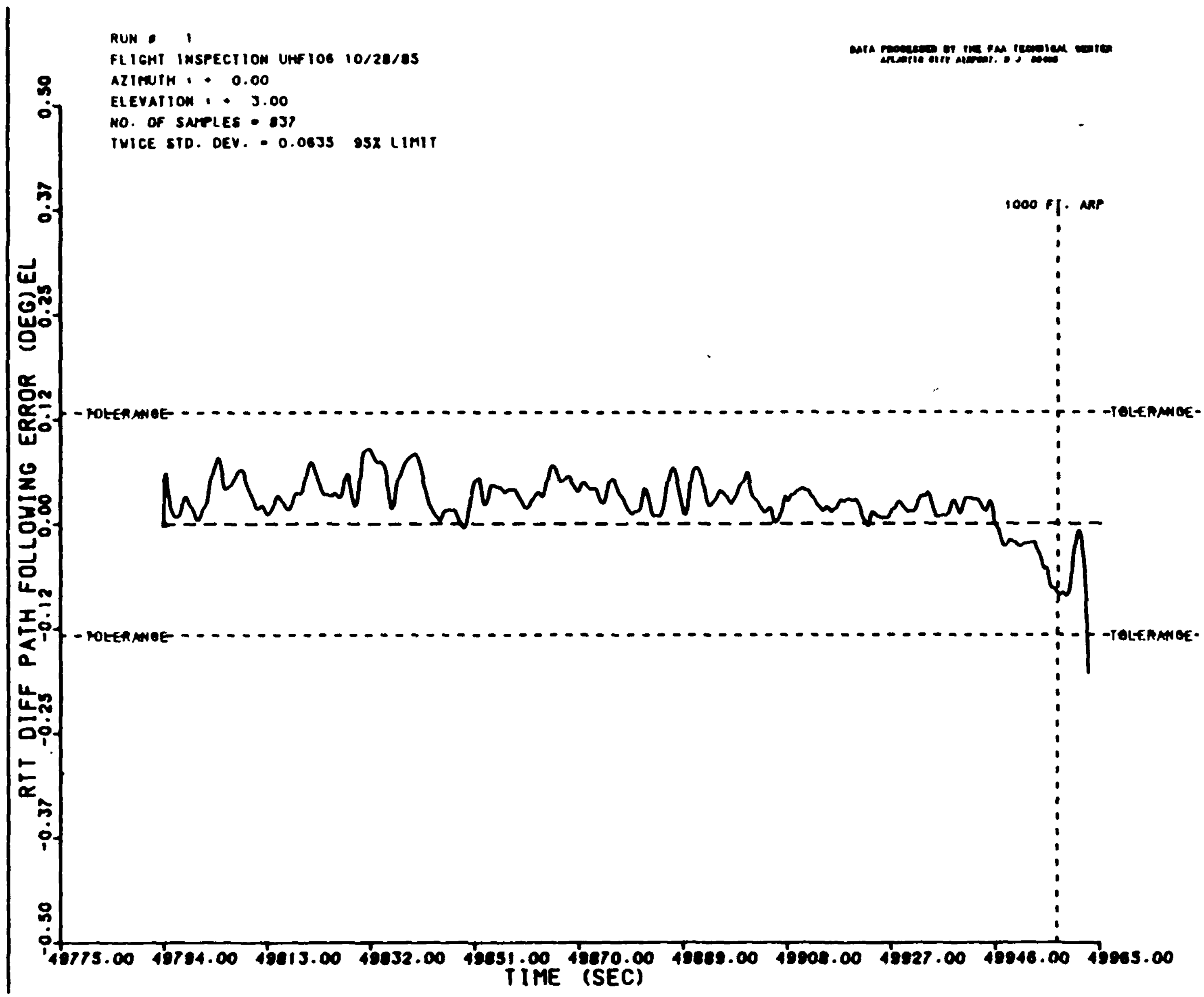


FIGURE 31. ELEVATION PFE RESULTS RUN 1, FLIGHT 6

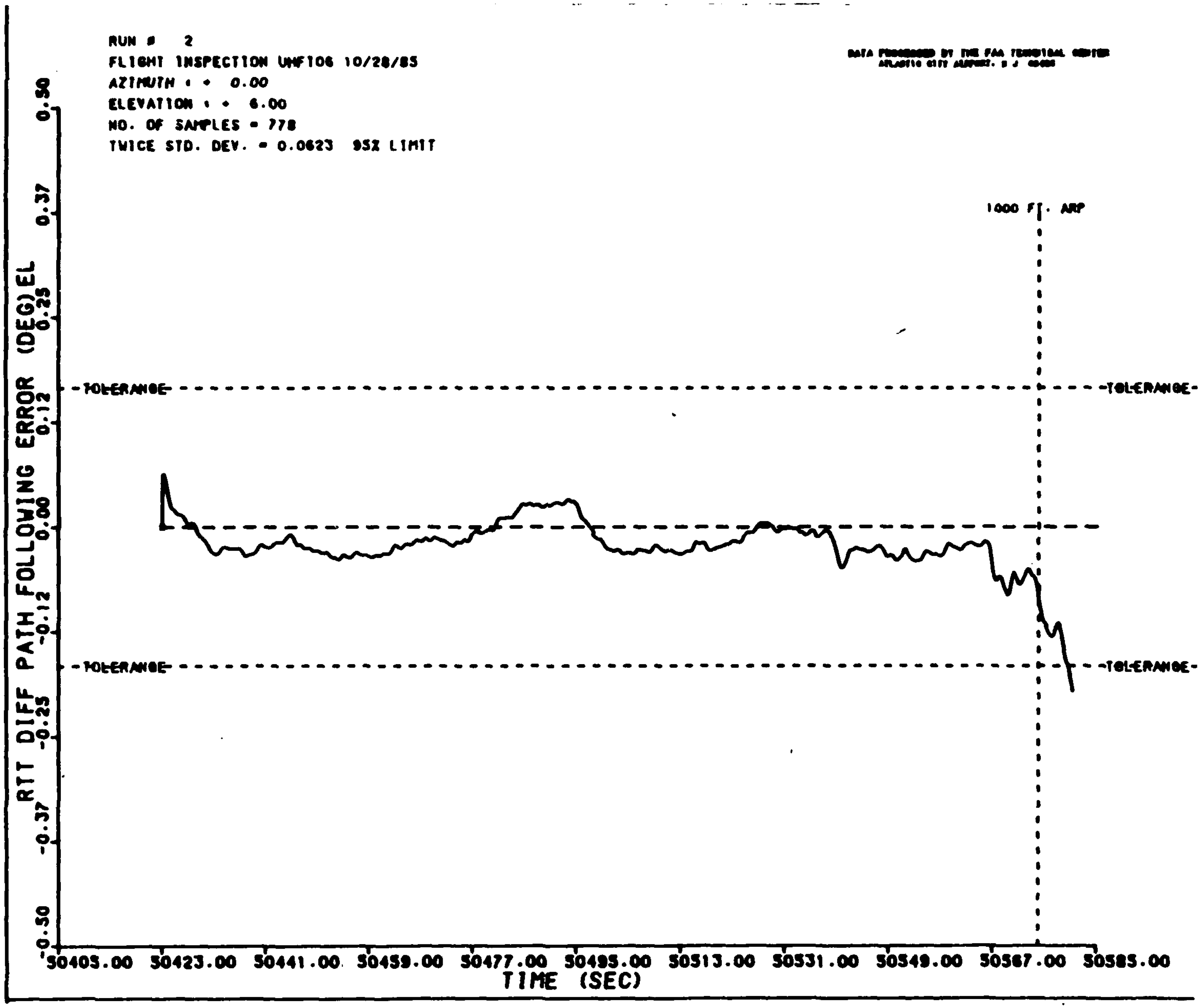


FIGURE 32. ELEVATION PFE RESULTS RUN 2, FLIGHT 6

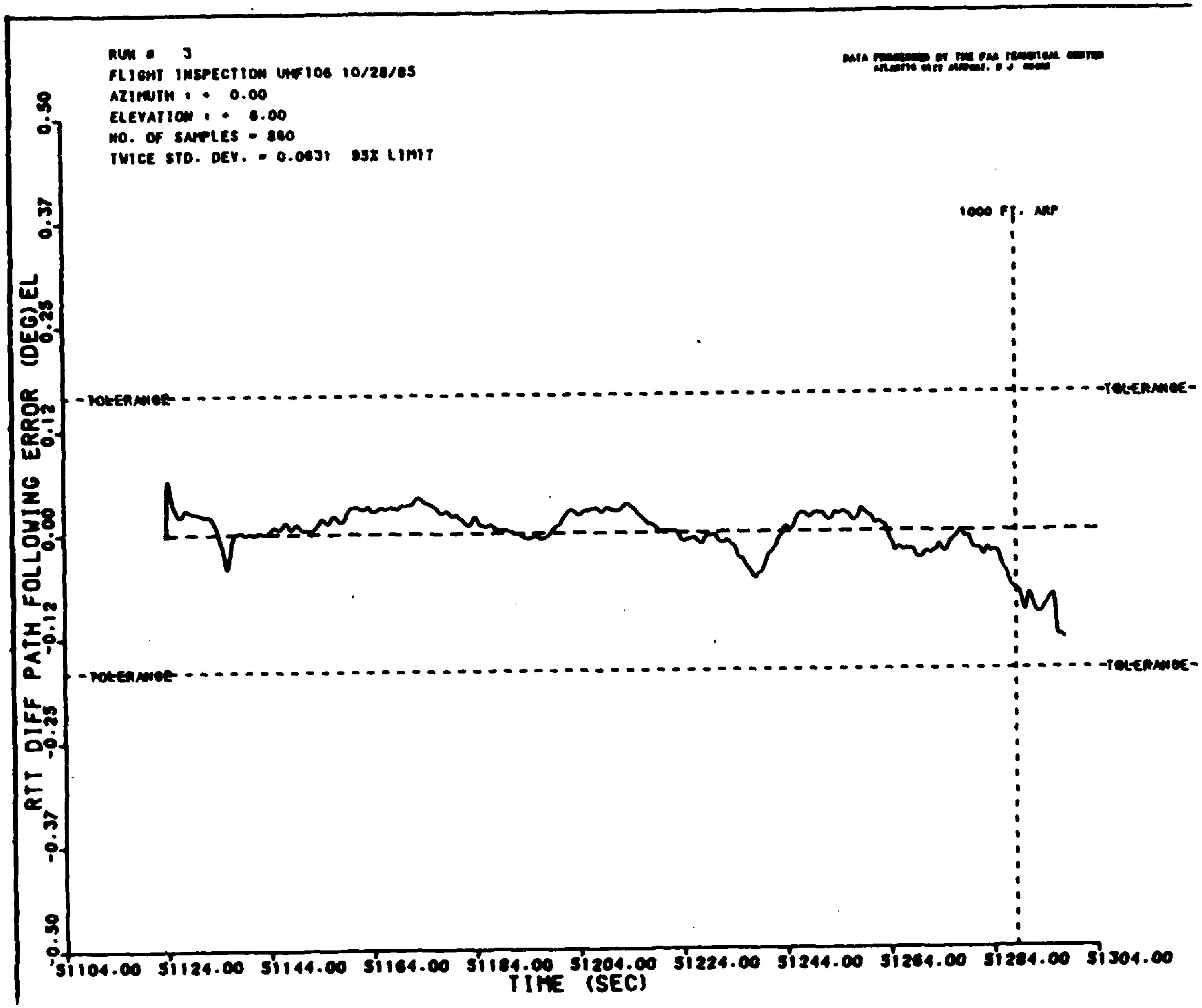


FIGURE 33. ELEVATION PFE RESULTS RUN 3, FLIGHT 6

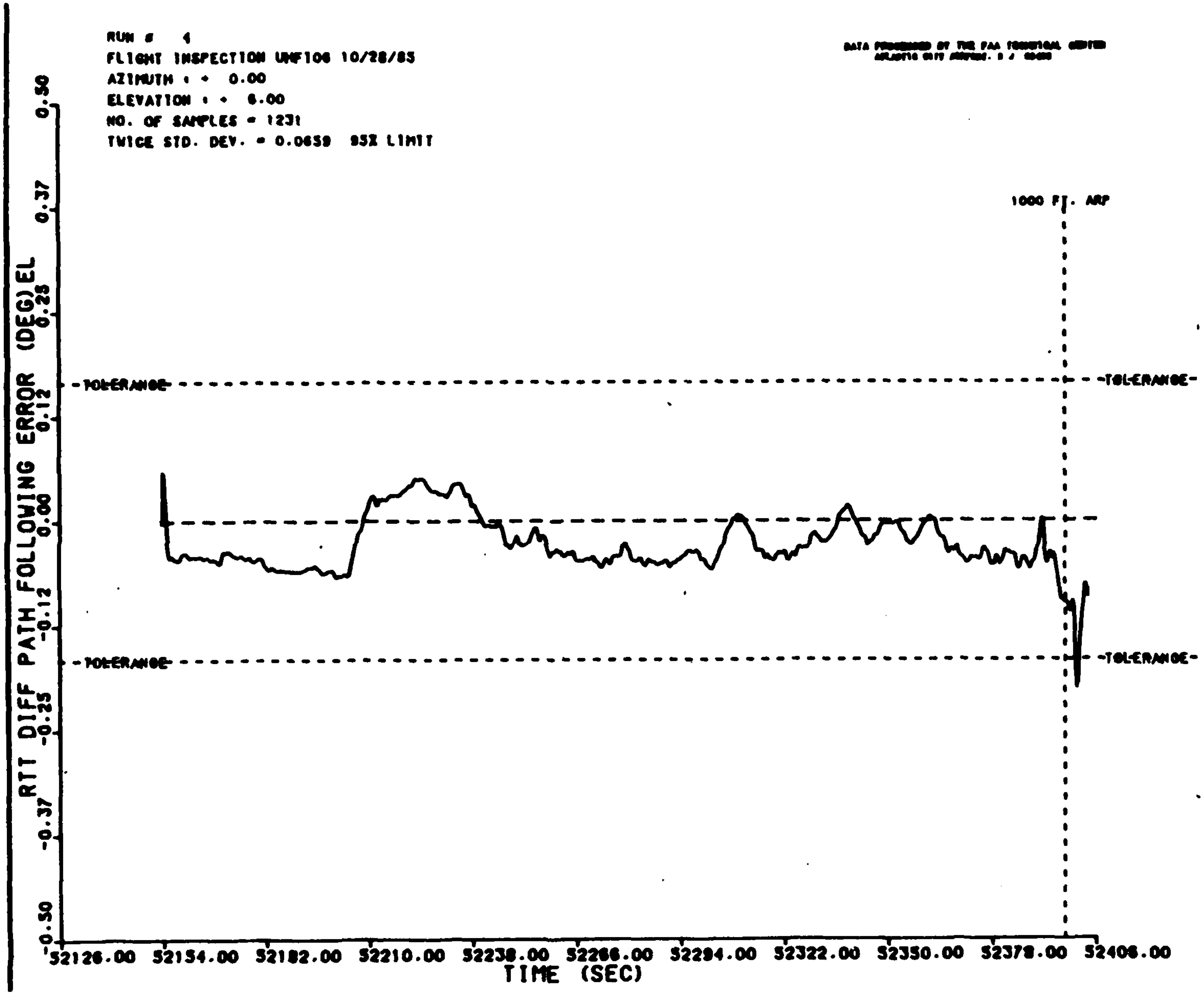


FIGURE 34. ELEVATION PFE RESULTS RUN 4, FLIGHT 6

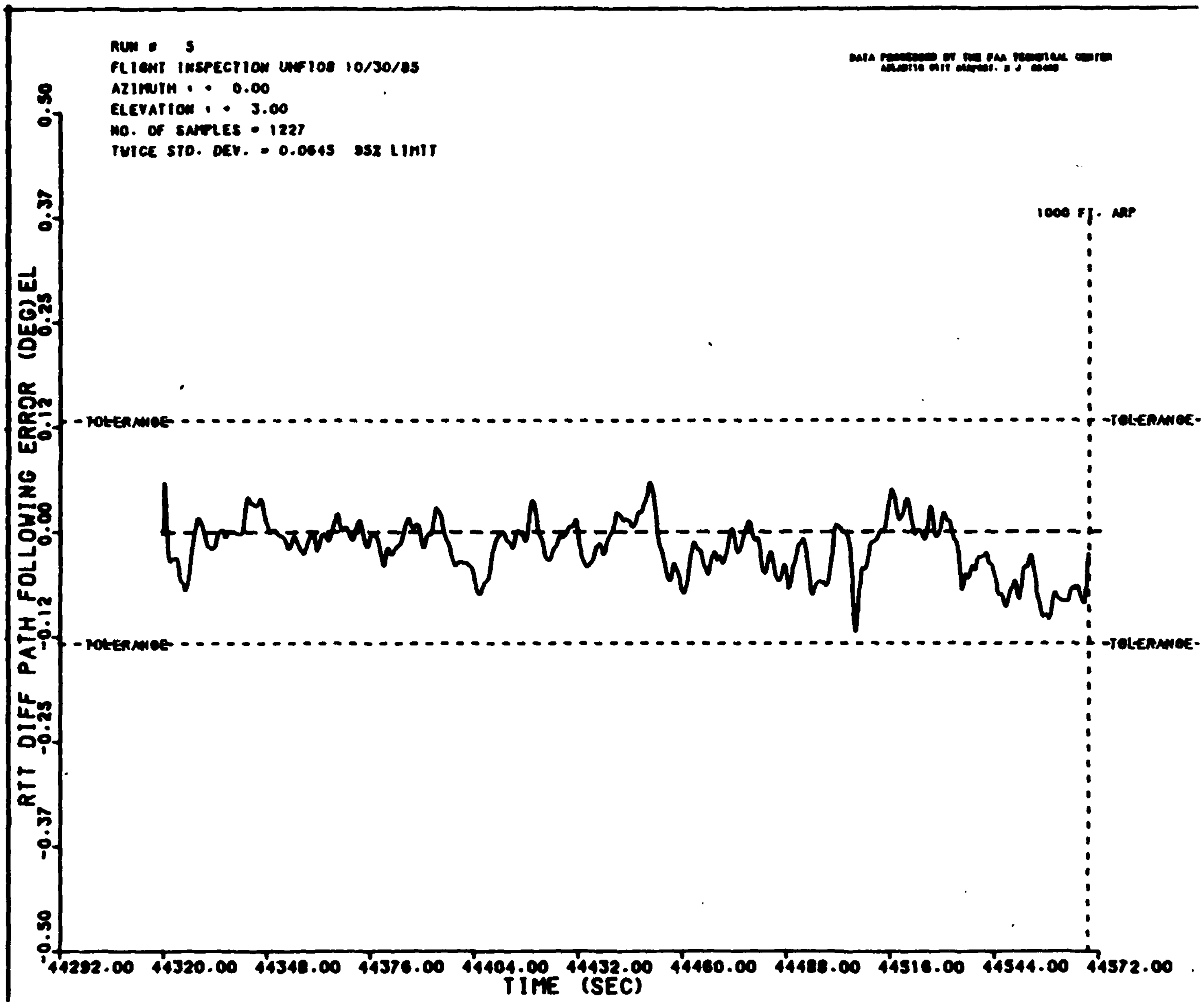


FIGURE 35. ELEVATION PFE RESULTS RUN 5, FLIGHT 8

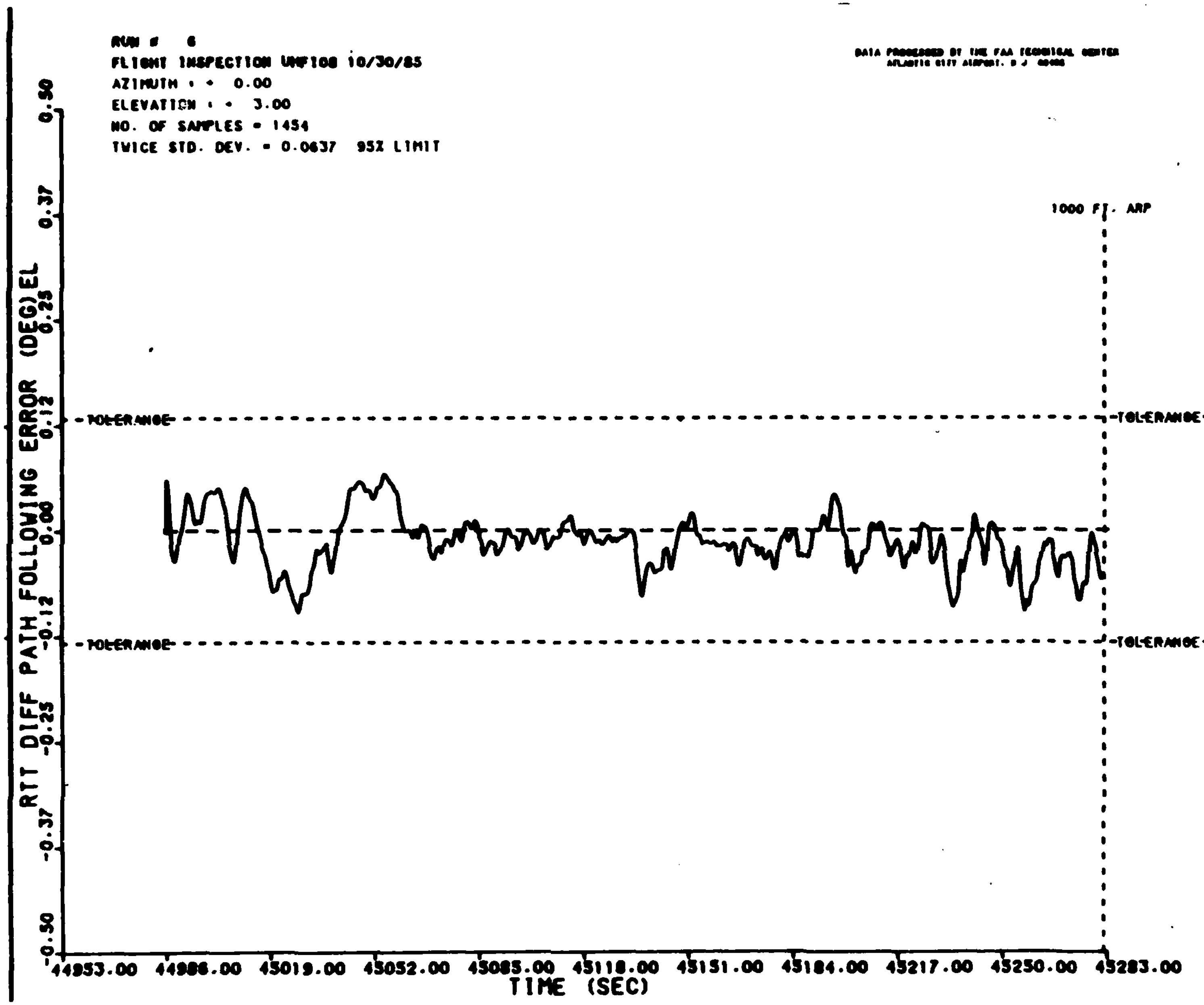


FIGURE 36. ELEVATION PFE RESULTS RUN 6, FLIGHT 8

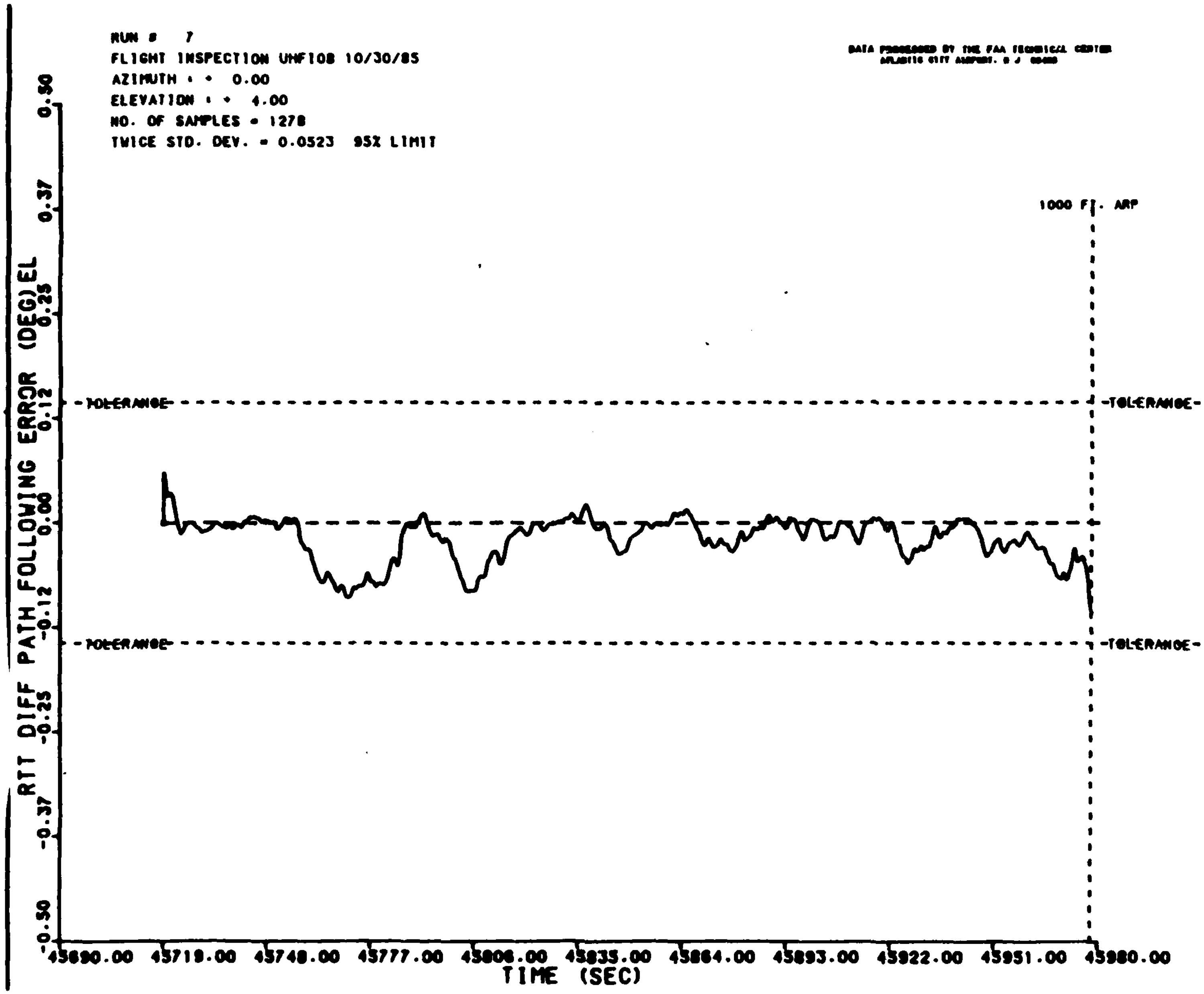


FIGURE 37. ELEVATION PFE RESULTS RUN 7, FLIGHT 8

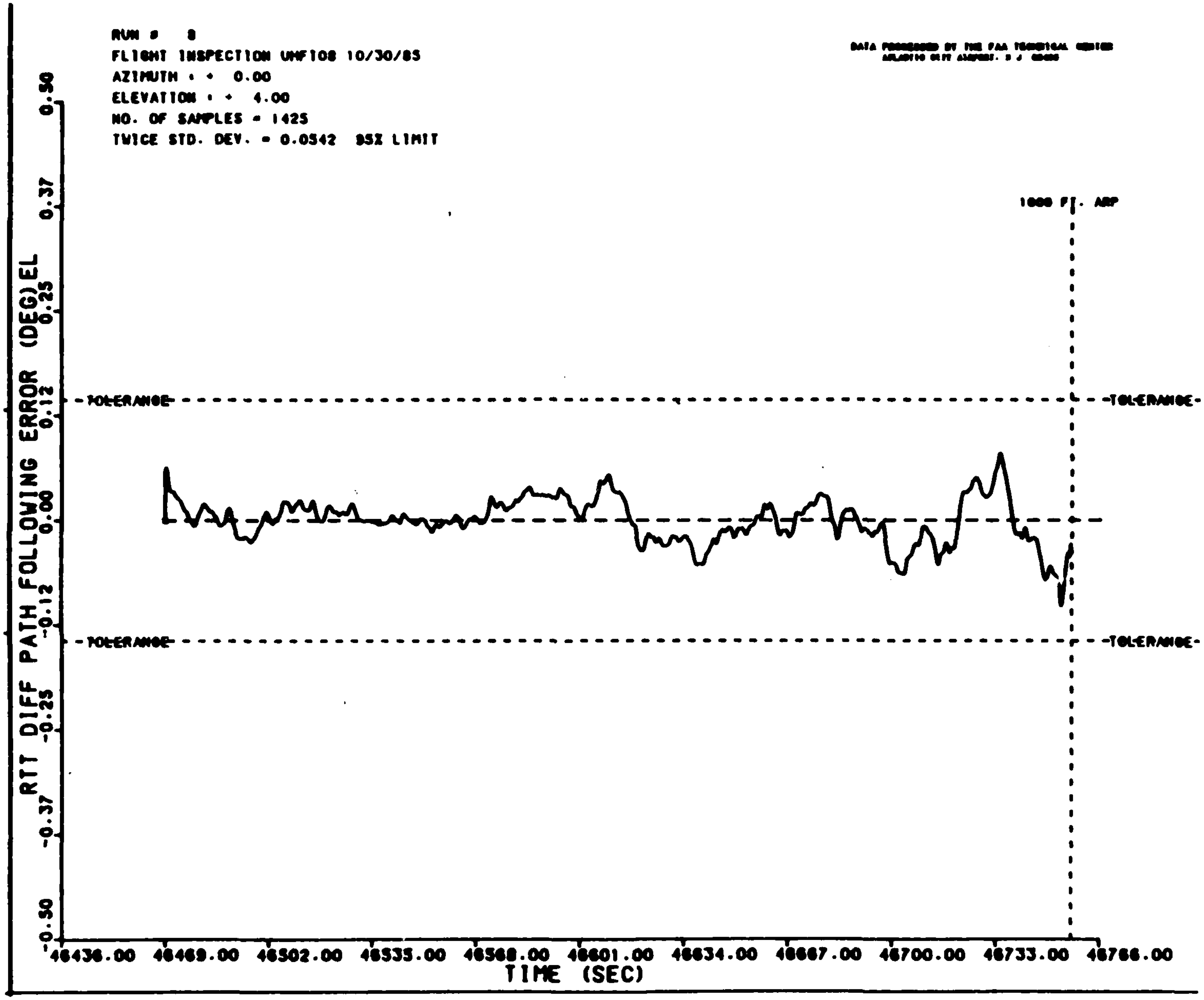


FIGURE 38. ELEVATION PFE RESULTS RUN 8, FLIGHT 8

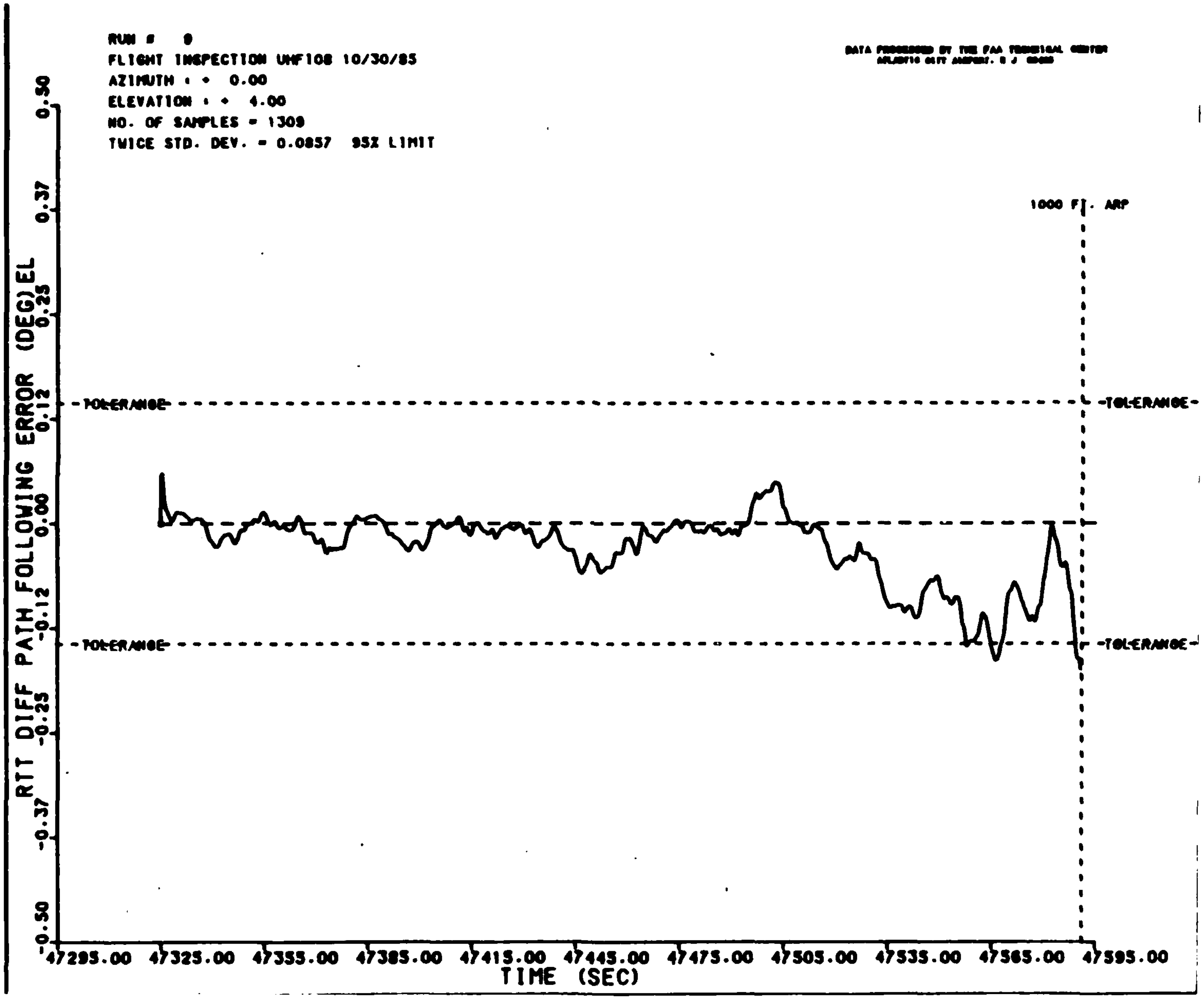


FIGURE 39. ELEVATION PFE RESULTS RUN 9, FLIGHT 8

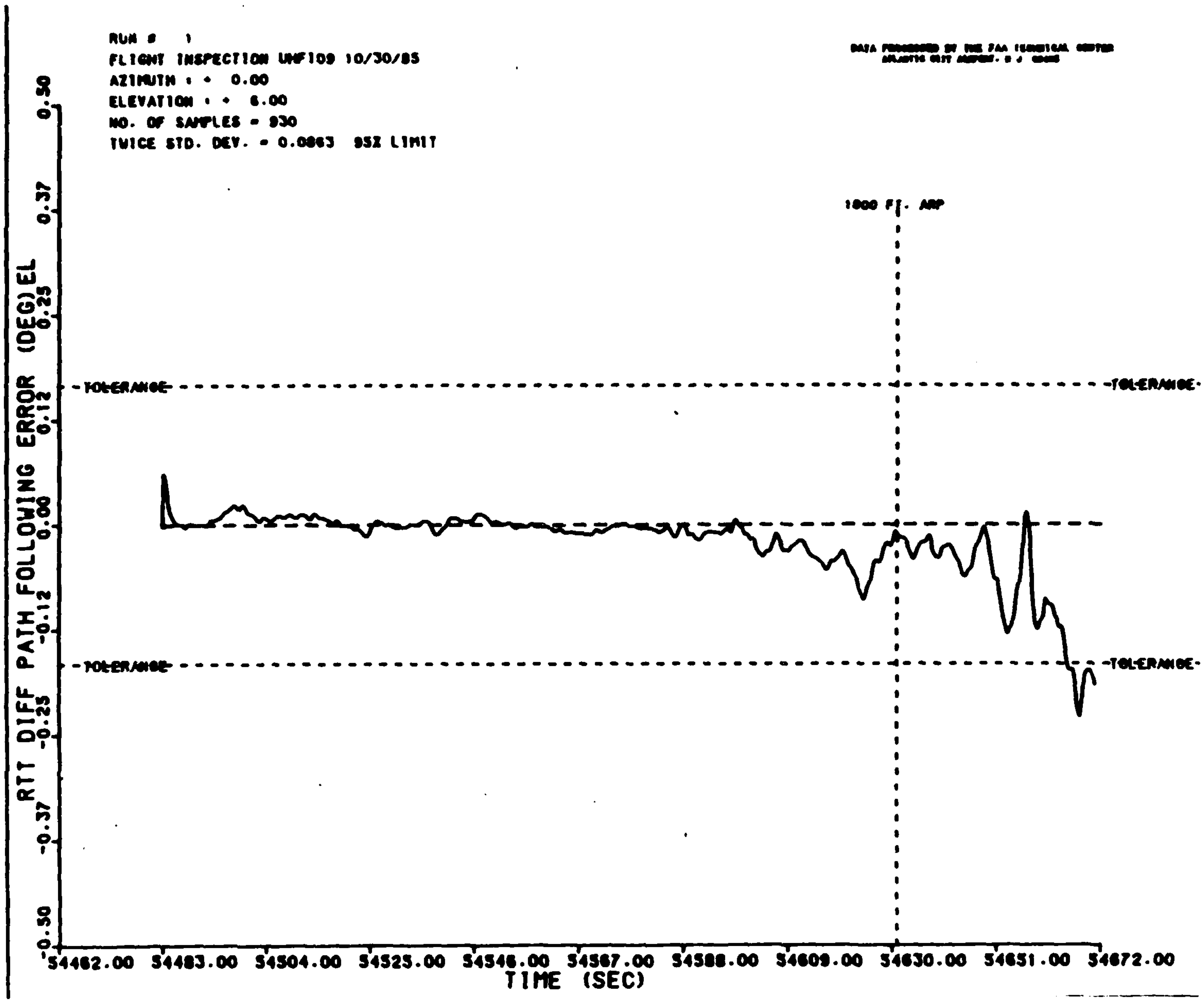


FIGURE 40. ELEVATION PFE RESULTS RUN 1, FLIGHT 9

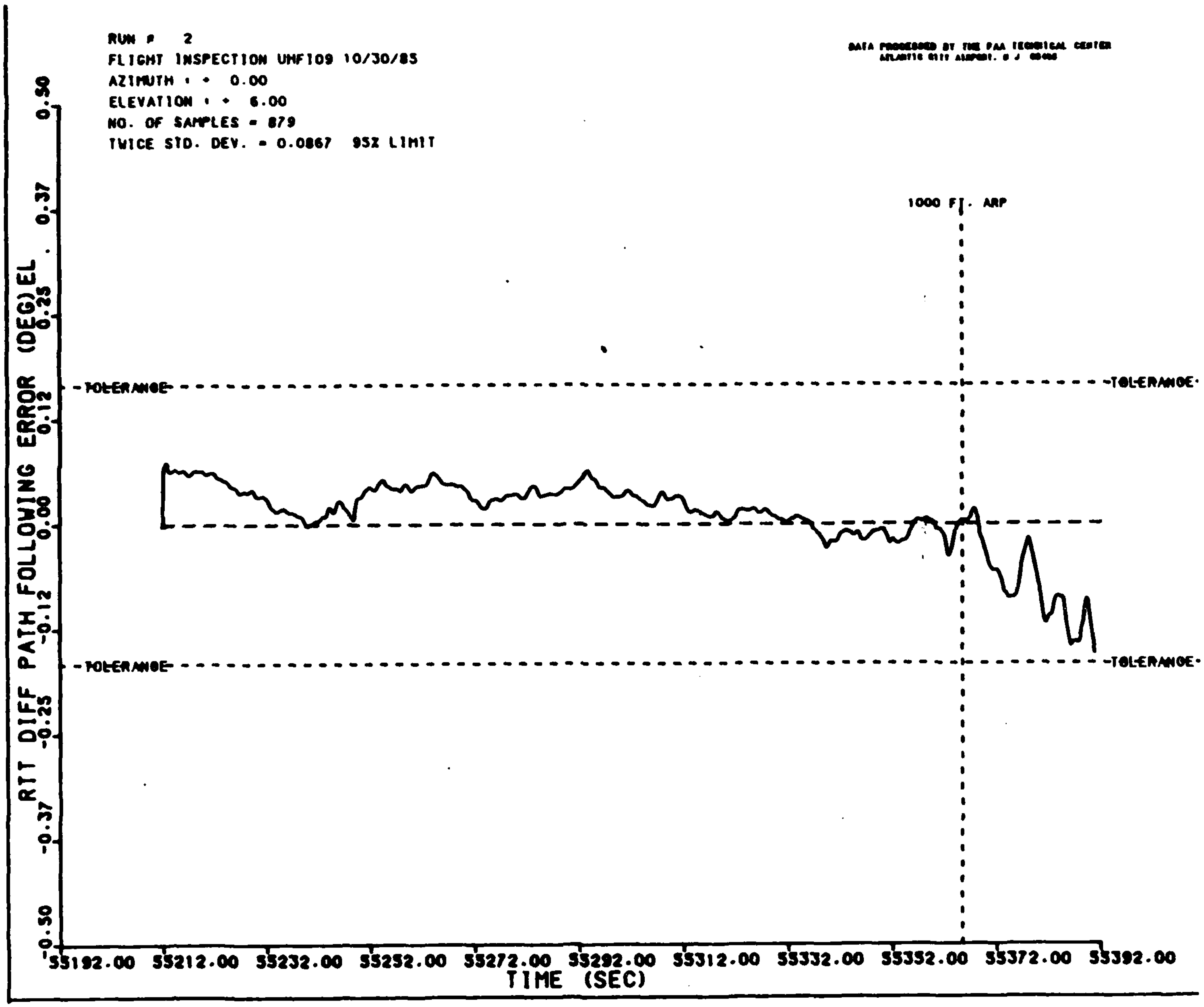


FIGURE 41. ELEVATION PFE RESULTS RUN 2, FLIGHT 9

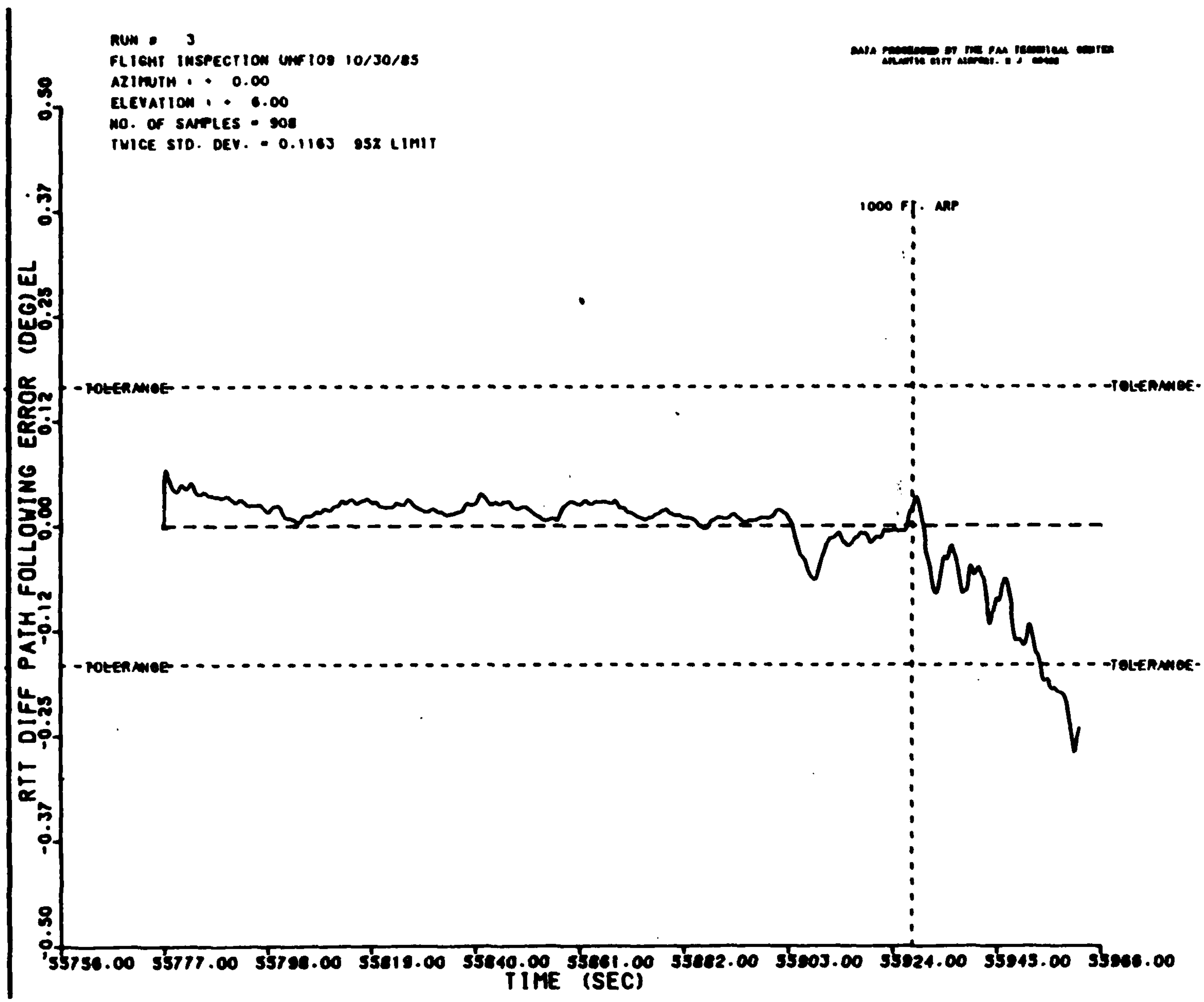


FIGURE 42. ELEVATION PFE RESULTS RUN 3, FLIGHT 9

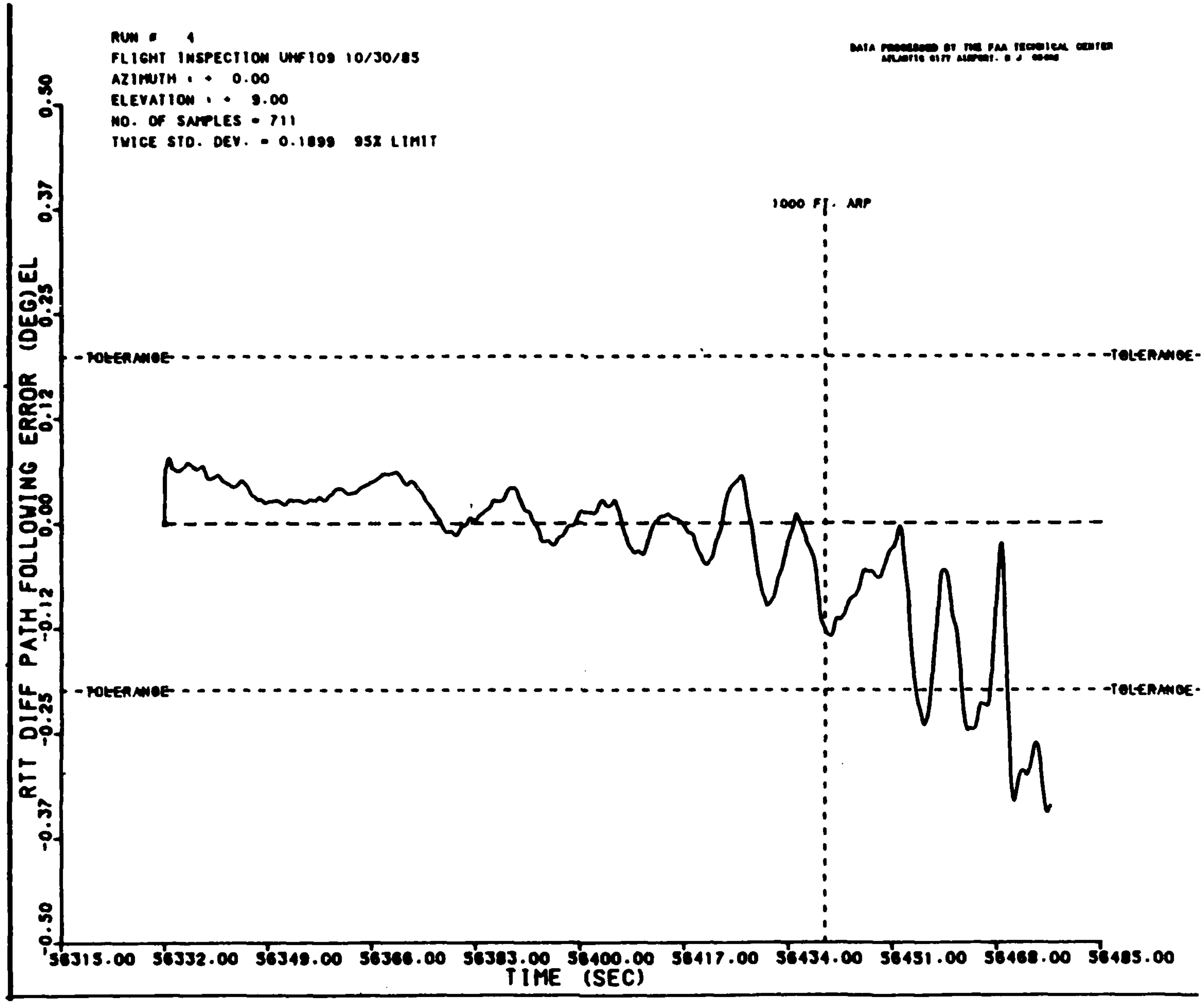


FIGURE 43. ELEVATION PFE RESULTS RUN 4, FLIGHT 9

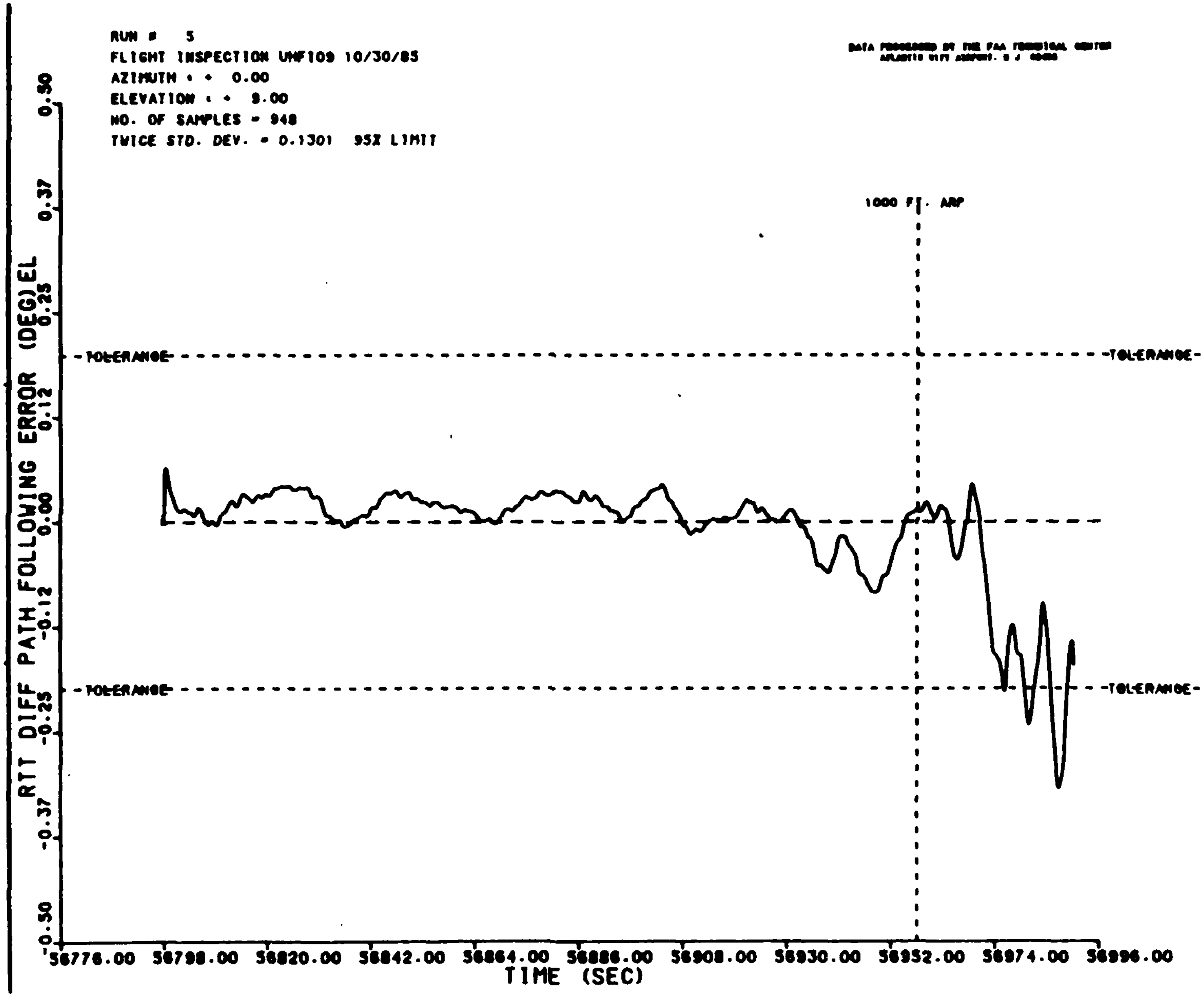


FIGURE 44. ELEVATION PFE RESULTS RUN 5, FLIGHT 9

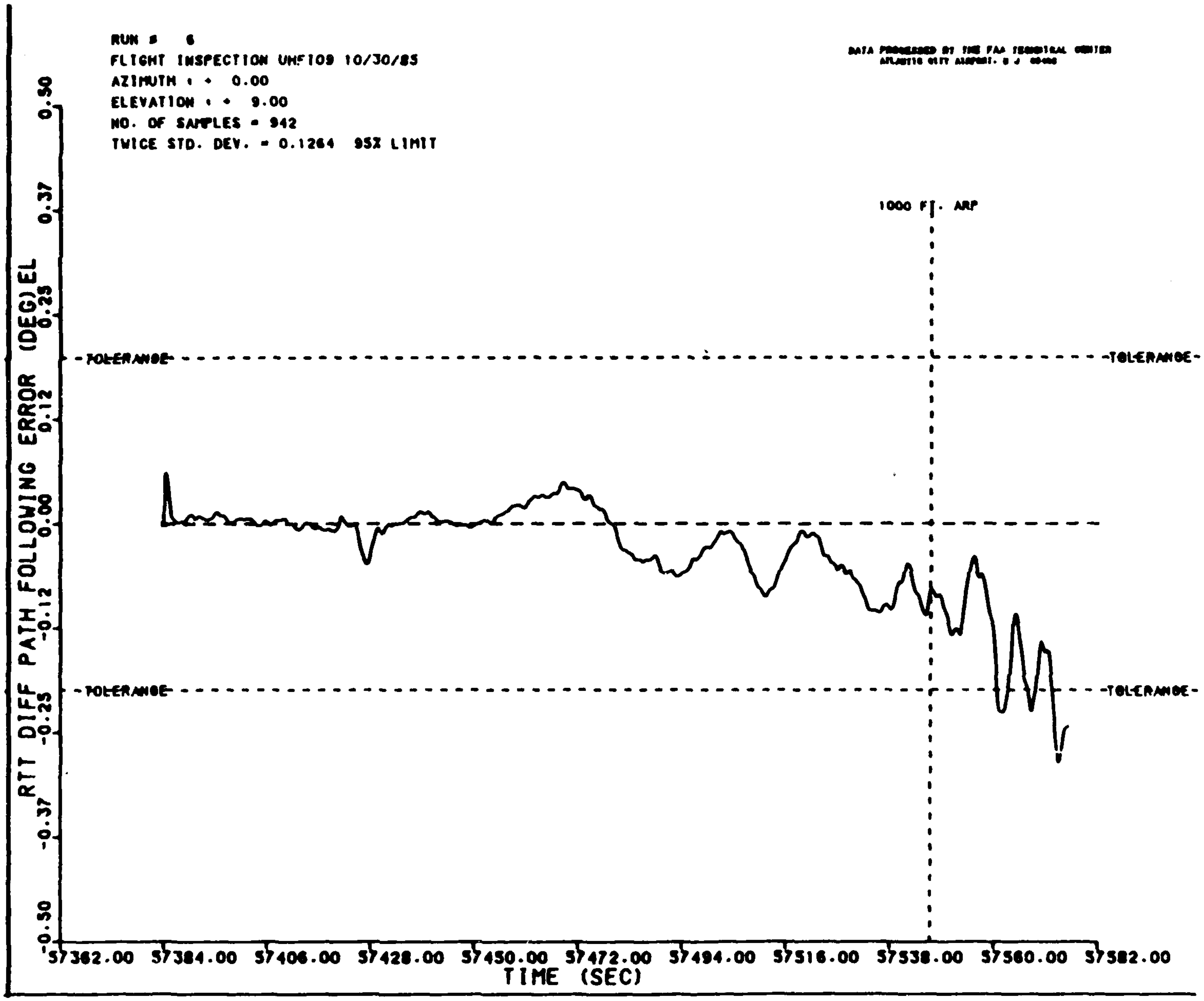


FIGURE 45. ELEVATION PFE RESULTS RUN 6, FLIGHT 9

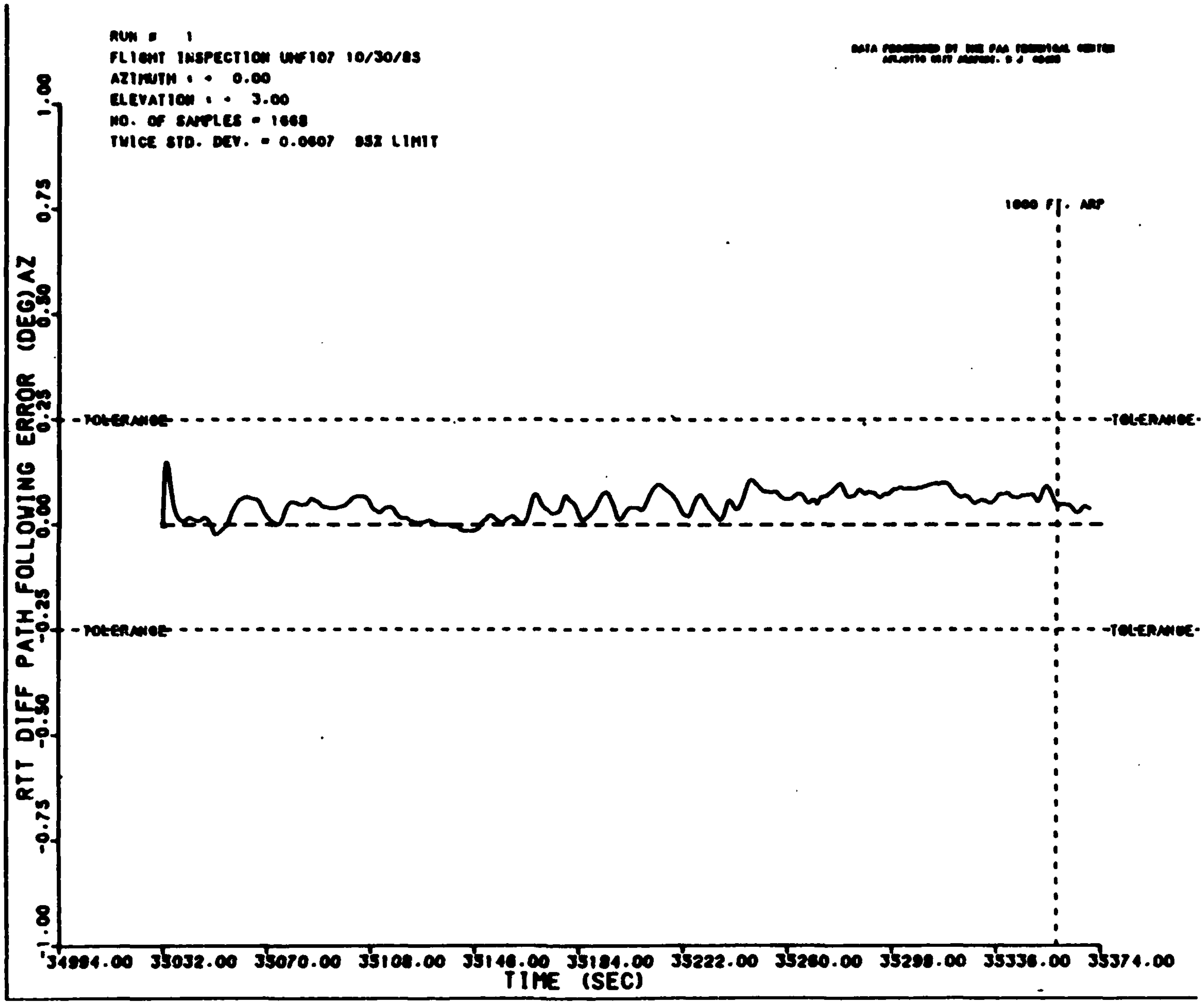


FIGURE 46. AZIMUTH PFE RESULTS RUN 1, FLIGHT 7

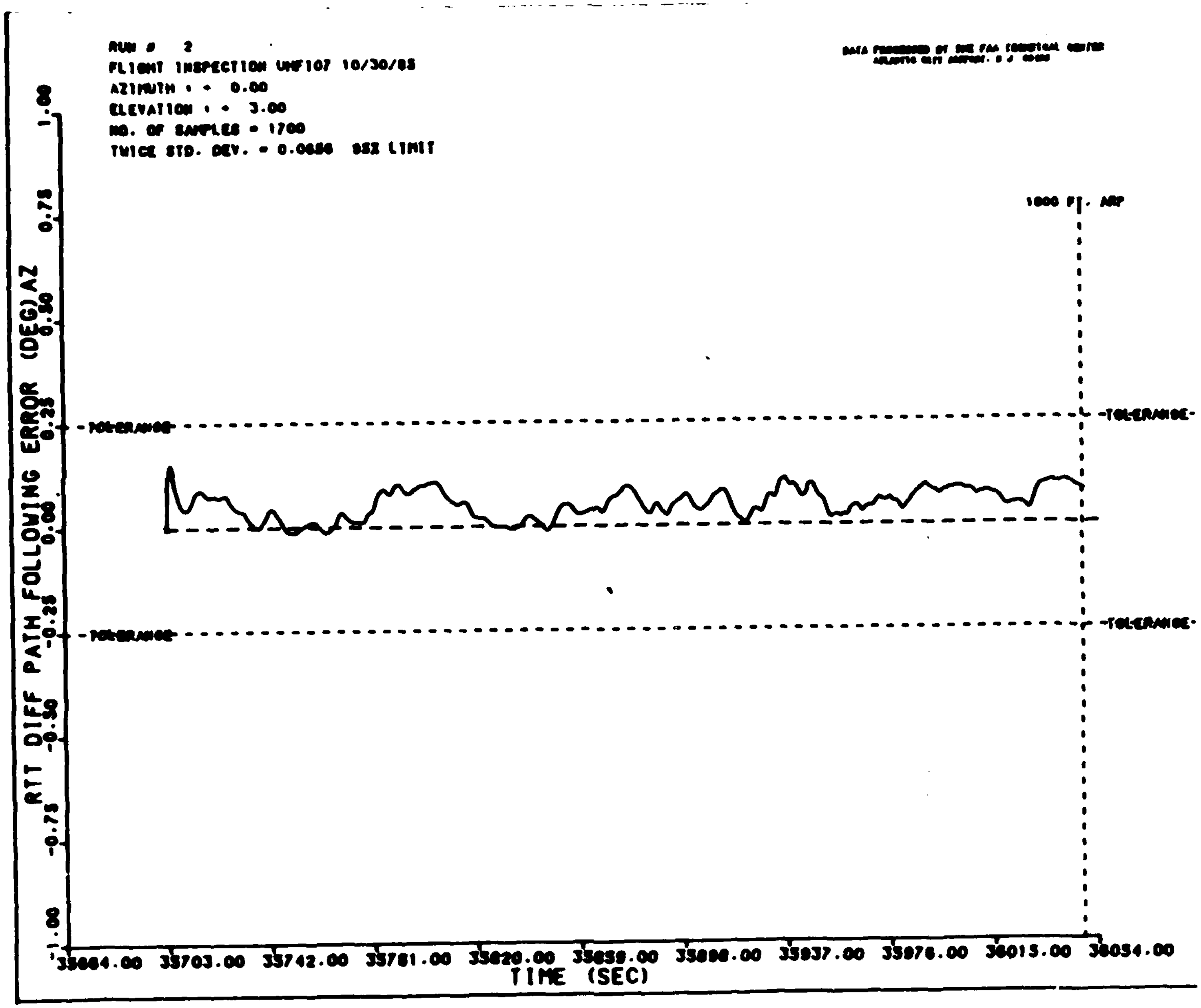


FIGURE 47. AZIMUTH PFE RESULTS RUN 2, FLIGHT 7

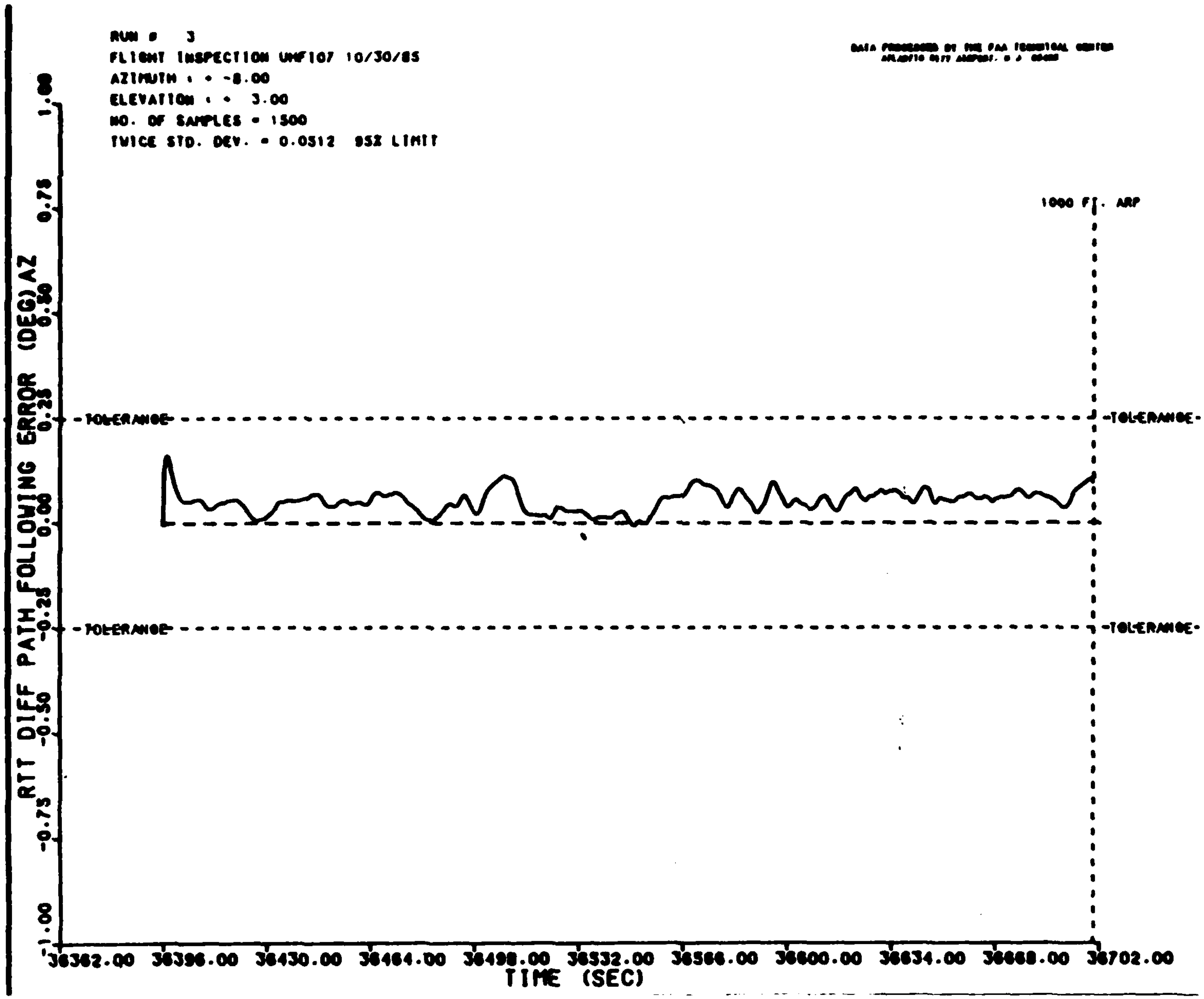


FIGURE 48. AZIMUTH PFE RESULTS RUN 3, FLIGHT 7

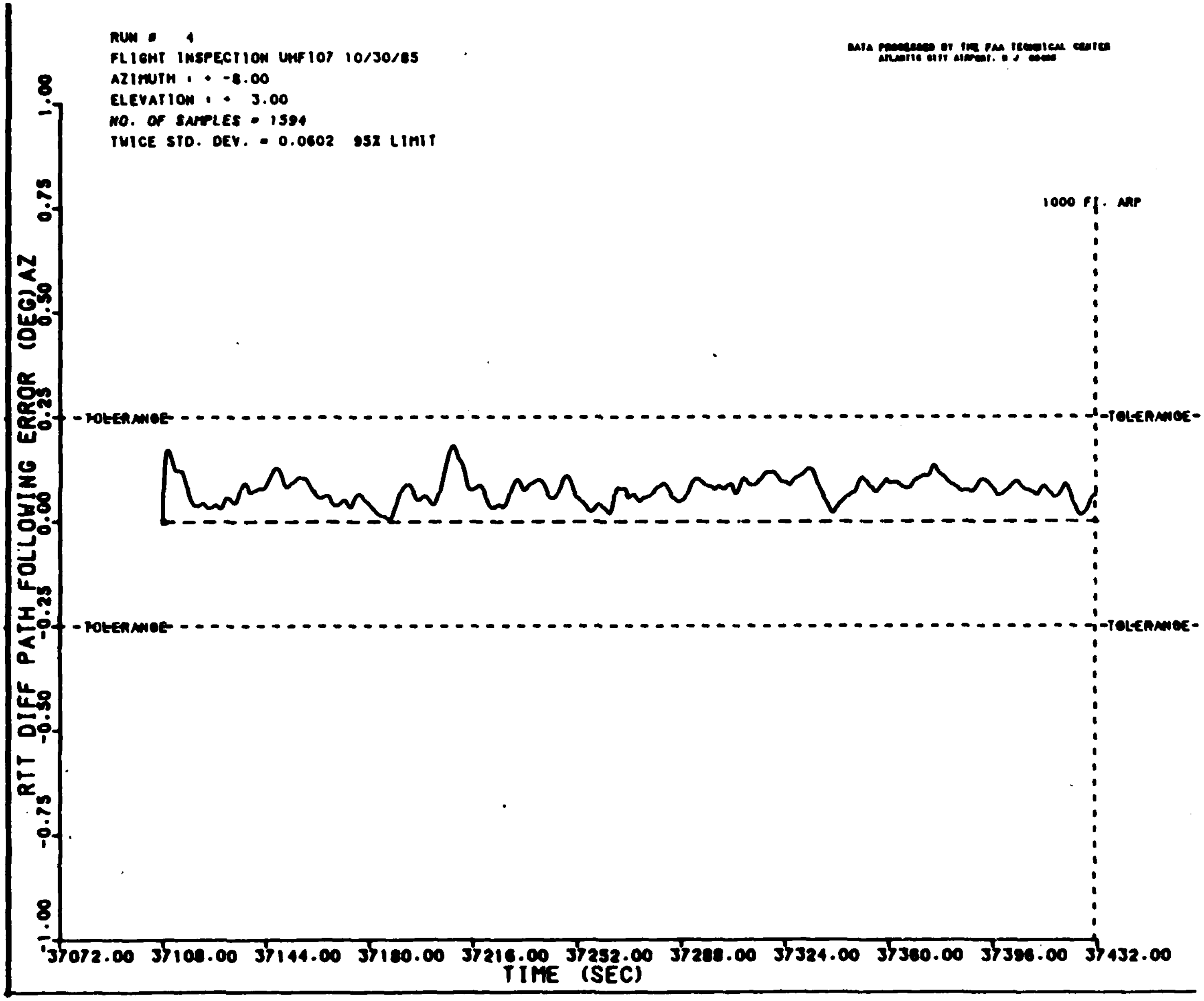


FIGURE 49. AZIMUTH PFE RESULTS RUN 4, FLIGHT 7

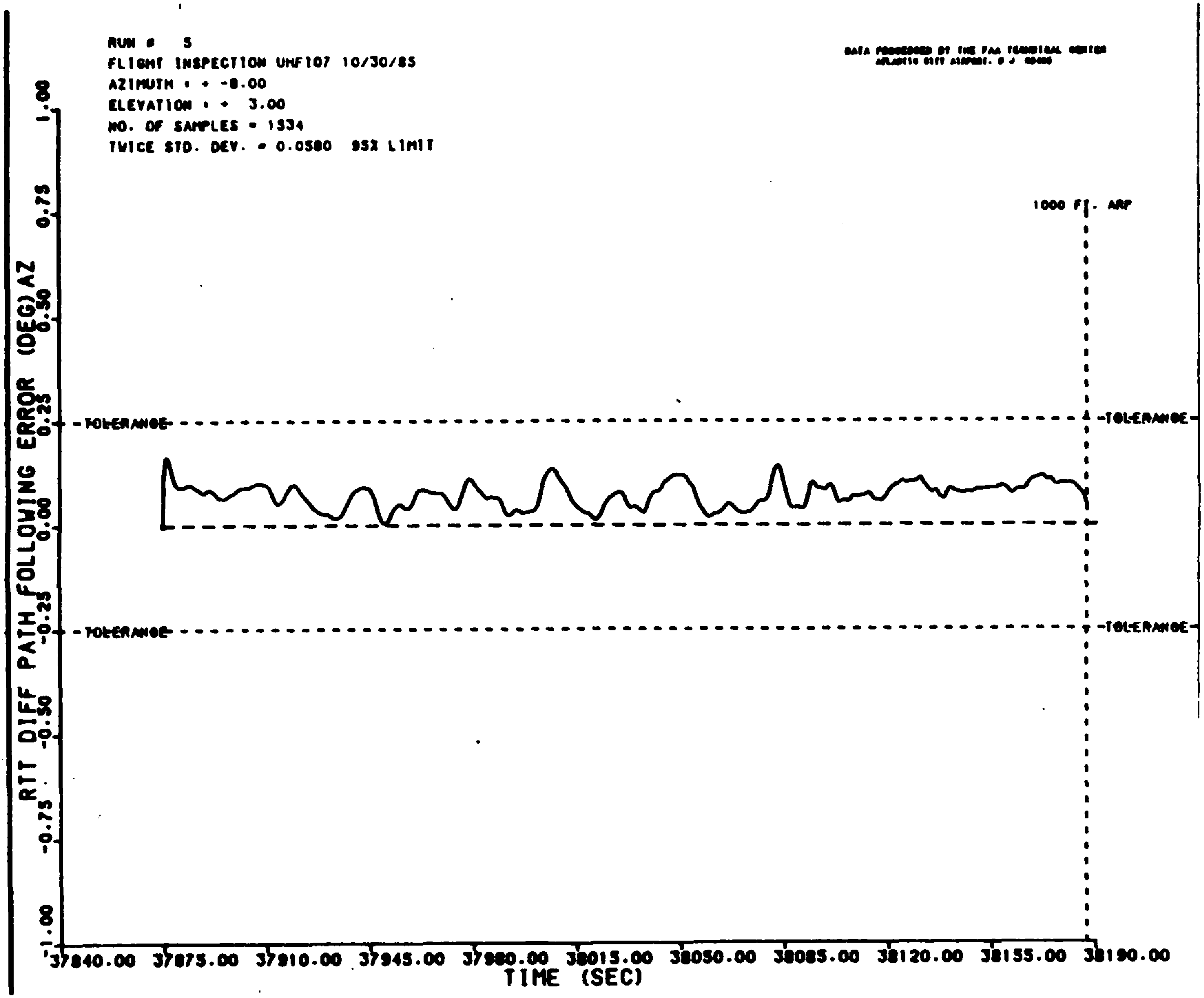


FIGURE 50. AZIMUTH PFE RESULTS RUN 5, FLIGHT 7

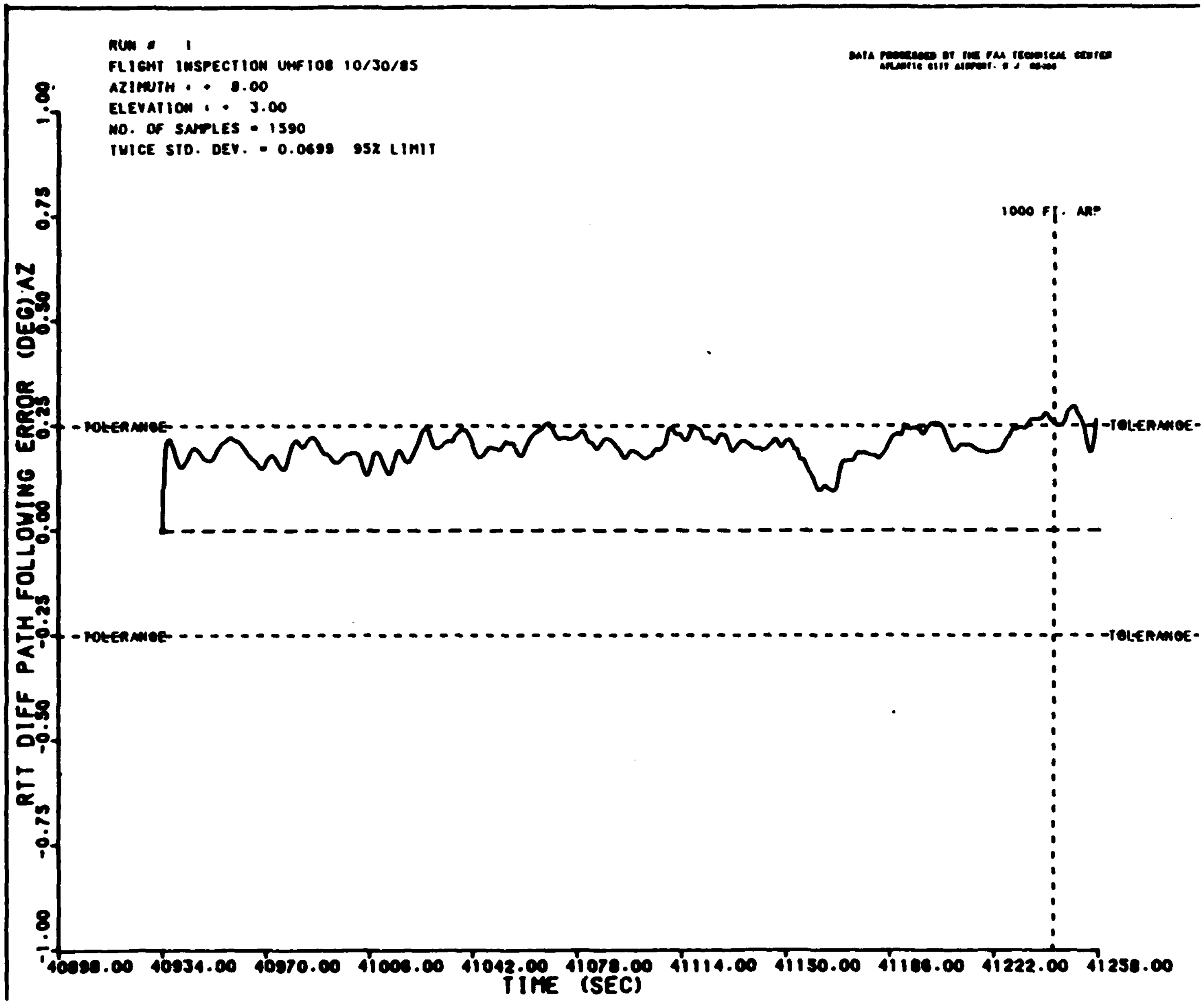


FIGURE 51. AZIMUTH PFE RESULTS RUN 1, FLIGHT 8

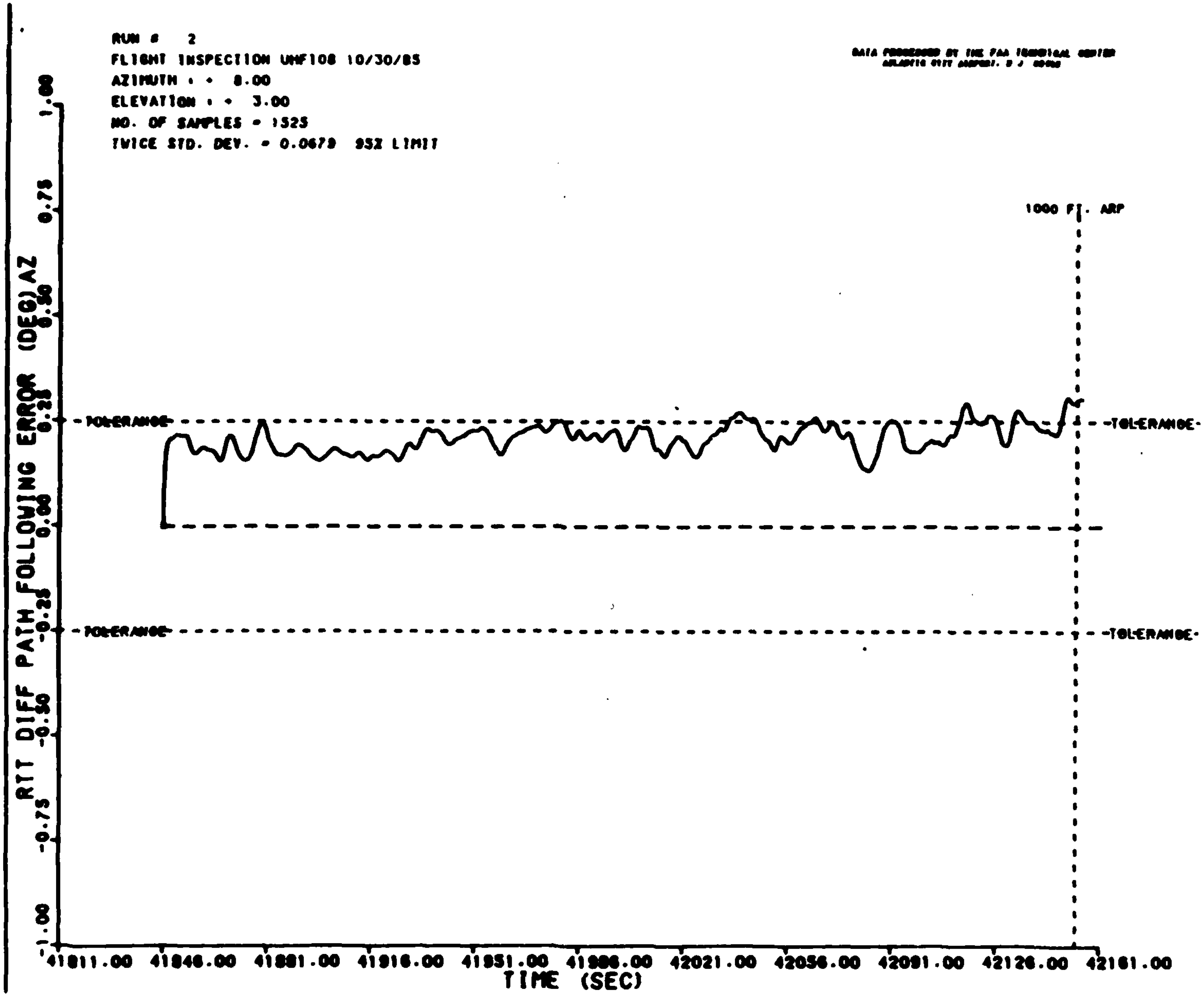


FIGURE 52. AZIMUTH PFE RESULTS RUN 2, FLIGHT 8

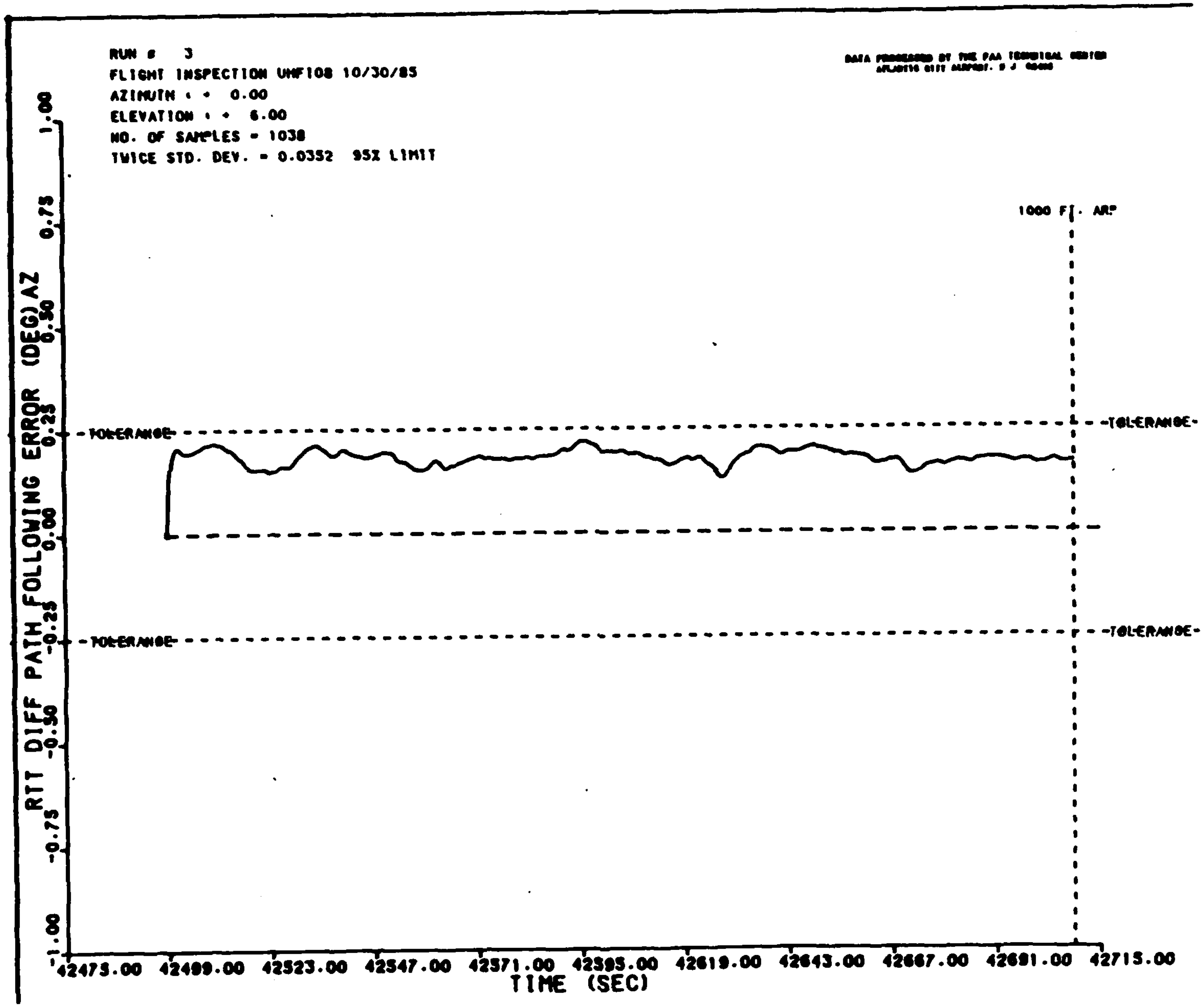


FIGURE 53. AZIMUTH PFE RESULTS RUN 3, FLIGHT 8

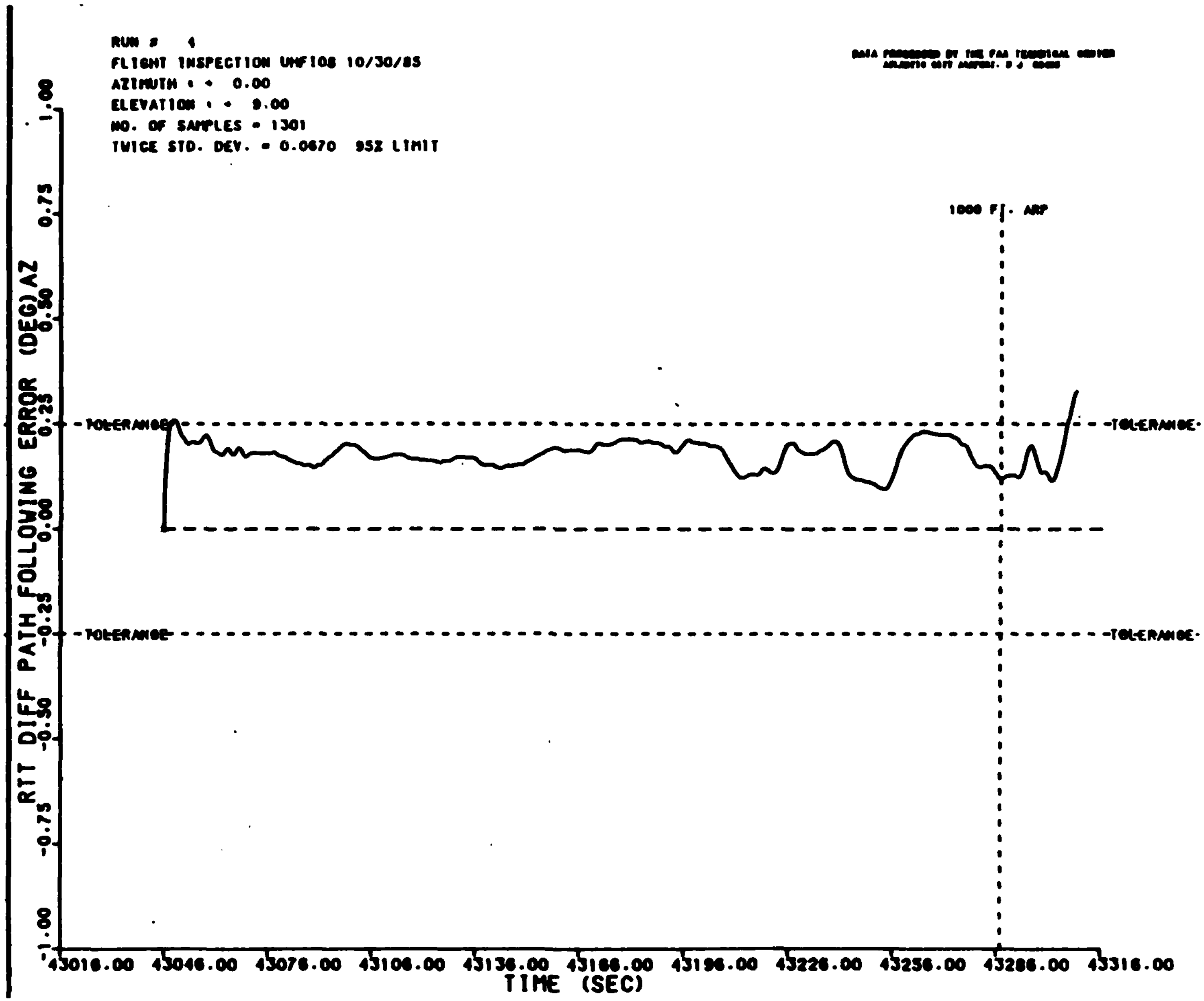


FIGURE 54. AZIMUTH PFE RESULTS RUN 4, FLIGHT 8

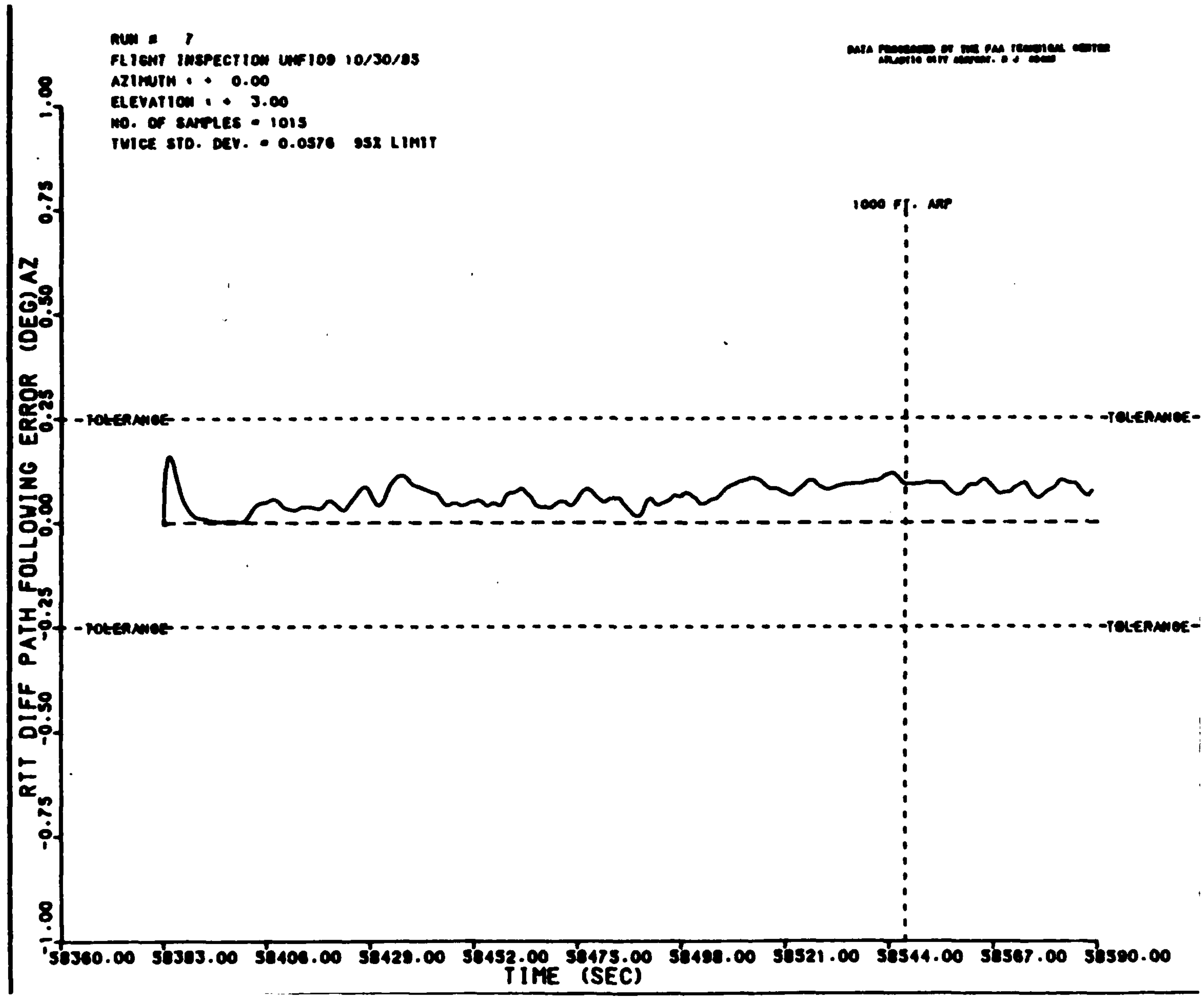


FIGURE 55. AZIMUTH PFE RESULTS RUN 7, FLIGHT 9

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